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The Role of Task Manipulations on the Invariant Phasing Characteristics of a Generalized Motor Program (Relative Timing).

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THE ROLE OF TASK MANIPULATIONS ON THE INVARIANT PHASING CHARACTERISTICS OF A GENERALIZED MOTOR PROGRAM

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by

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FOREWORD

This dissertation has been written in the style adopted by the American Psychological Association for submission to scholarly journals. Pages 1-78 represent the body of the manuscript as prepared for journal submission. The remaining pages constitute the appendix, and consist of some background issues on a centralist versus peripheralist approach to movement control, tables of MANOVAS and ANOVAS, and means and standard deviations.

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ABSTRACT

Four experiments are reported that investigate the role of relative timing as an invariant characteristic of the generalized motor program. Based upon the concept of a generalized motor program, relative time as an invariant characteristic, should remain constant when variant features of a movement are manipulated. In the present series of experiments, a practice and transfer paradigm was used to investigate the influence of required parameter modifications on the relative timing characteristics during the transfer performance of a practiced three-component movement response. Following 150 training trials (100 trials on Day 1 and 50 trials on Day 2), subjects (n=12) were randomly assigned to 1 of 10 transfer conditions that manipulated the variant features of the training task. Fifty transfer trials were performed that differed from the training task in terms of the geometric, dimension, direction or muscle selection characteristics. Results based on group analysis of variance and individual linear regression, indicated that for all parameter characteristic manipulations, relative timing patterns during transfer performance deviated significantly from those established during training trials. These results are in contradiction with previous studies which have supported the idea that timing structure remains invariant across changes in muscle selection and event duration. However, since the absolute magnitude of the relative timing proportion changes were so small, typically from .5 to 2%, a modification in the current definition of relative timing invariance is suggested rather than an abandonment of the construct as a generalized motor program feature.

The Role of Task Manipulations on the Invariant Phasing

Characteristics of a Generalized Motor Program

The motor program is a currently popular construct considered to be the mechanism responsible for controlling rapid actions. Originally the motor program was viewed as a centrally based series of muscle commands that controlled actions without the possibility of involvement from peripheral feedback (Lashley, 1917; Henry & Rogers, 1960; Keele, 1968). The original motor program concept also postulated that a separate motor program was specific to variations in individual movements (Henry & Rogers, 1960). This idea presented a problem in terms of the amount of information to be stored in the central nervous system (McNeilage & McNeilage, 1973; Schmidt, 1976). Based upon the inefficiency of storing a separate motor program for every action, Pew (1974) and later Schmidt (1975) suggested that once formed, the motor program is generalized in some fashion such that related patterns of movement are under its control.

The generalized motor program is stored in memory and contains information that will result in a unique pattern of action when the program is executed. The patterns of action exhibited by the generalized motor program are unique due to the addition of certain parameter values specific to individual movement responses. It is the addition of the parameter information that allows the motor program to be generalized. Evidence for this broadened view of a motor program has been obtained by observing behavior under a variety of changing parameters and searching for common patterns that can be related to invariances or commonalities across a variety of movement responses (Schmidt, 1985).

Along similar lines Bernstein (1967) has suggested that movements which are within the same movement class should also employ the use of similar engrams (or programs) of control. In order for two movements to be within one movement class they must share similar topological properties. Topological properties refer to the geometrical representation of a particular movement pattern. For example, a topological class of five-pointed stars has five angles or points and five intersecting lines. These stars can be any size or have any orientation in space. These characteristics allow five pointed stars to be easily distinguished and recognized in spite of their actual physical dimensions. An abstract representation of a motor image in space of a particular topology is considered to be specified within the central nervous system. This representation is sensitive only to spatial rather than the dimensional or metrical aspects of movement production. From Bernstein's point of view, movements which share the same topological class are governed by the same abstract representation of the particular pattern of action. This view, although not commonly associated with Schmidt's (1975) and Pew's (1974) view of the structure of a generalized motor program, is actually very similar.

Two features that have been commonly associated as characteristics of a generalized motor program have been labelled as variant and invariant characteristics (Schmidt, 1975; 1982). The features of a movement that seem to be easily modified without restructuring the patterns of commonalities within related movements have been termed variant (parameter) characteristics. According to

Bernstein (1967) and Schmidt (1982) movement features which would be expected to be easily modified are ones that vary a movement's dimension, overall speed, overall force, direction, or the muscle selection employed in order to perform the movement. By manipulating these variant features of the action, movement patterns within the task may outwardly vary while the underlying deeper features or invariances of the action remain unchanged.

Two specific features of a movement that have been found to be resistant to change are the relative force and the relative time characteristics of a movement response. Relative force refers to the relative sizes of the forces of two muscular contractions. If the central structure for two movements is similar then the relative sizes of the contractions of the muscles required to produce the response remain constant across changes in overall MT and movement size.

The second feature, relative time, has consistently exhibited invariances across changes in parameter values of movement responses and is the measure of interest in this investigation. According to Schmidt (1982), movements characterized by invariant relative timing within a generalized motor program are based upon a multiplicative rate parameter. That is, the durations of all components of the sequence of movements of an action, as represented in the generalized motor program, should remain in constant proportion of the overall duration, even when the overall duration of the sequence changes. Therefore, the role of the generalized motor program is to provide the structure of a series of pulses of motoneuron activity to the relevant musculature. If two movements are similar and share the same underlying program structure, then the ratios of the EMG durations among various muscle groups would have the same temporal structures. That is, the onsets and offsets of neuromuscular activity would be proportionally equal to movements which employ the same generalized motor program, yet outwardly vary in movement performance which reflect variations in duration, muscle selection, or movement direction. Therefore, if movements are controlled by the same generalized motor program, then the total movement speeds up or slows down by changing parameter values without altering the underlying temporal structure relationships (the relative time) of the various movement components.

Evidence supporting a relative timing invariance characteristic has come from investigations using a variety of tasks. Motor skills such as typing (Gentner, 1982; Terzuolo & Viviani, 1979), handwriting (Hollerbach, 1981; Merton, 1972; Raibert, 1977), locomotion (Shapiro, Zernicke, Gregor, & Distal, 1981), sequential hand-movement tasks (Armstrong, 1970; Shapiro, 1978), sequential key presses (Summers, 1976), horizontal lever positioning (Quinn & Sherwood, 1983), and discrete aimed responses (Langley & Zelaznik, 1985) have provided initial support for the invariance of relative time. By determining the total duration of a response and by defining individual component parts of the movement response, these investigators have compared the temporal pattern of a movement with one produced in a speeded-up or slowed-down version of the practiced task. In these situations movement patterns were argued to be under the control of the same motor program if the phasing characteristics of the novel task were similar to the task that was first performed.

For example, Summers (1976) trained individuals to make a series of rhythmical key presses. Following training trials on the key-pressing task, subjects were transferred to a novel condition where they were instructed to disregard the previously learned temporal characteristics of the task and where they were instructed to respond as quickly as possible. Although the overall speed of the response increased, the temporal pattern that was established during the training trials influenced the timing pattern of the novel task so that it was similar to the original performance. In this experiment, the actual movement speed varied while the underlying structure of the temporal relation remained unchanged.

Two limitations exist within the work published thus far supporting the invariance of relative timing. First, the tasks chosen by many researchers (Armstrong, 1971; Carter & Shapiro, 1984; Shapiro, 1977; 1978; Summers, 1977) employed learning a series of movement sequences to experimenter-defined criterion times. One of the problems with using component tasks with specific criterion times is that even after many days of practice, subjects do not become very accurate at producing responses in which criterion times are specified (see Gentner, 1985 for recent criticsm). The second limitation to these works is that all studies investigated relative timing characteristics when overall duration either speeded up or slowed down. Therefore, with the exception of handwriting research, the previous literature provides no information about the ability of the generalized motor program to exhibit invariances in relative timing when parameter manipulations involve varying direction, physical dimension, or geometrical configurations.

Although a large body of evidence has supported the notion of relative time as an invariant characteristic (see Schmidt, 1985, for a review), some debate recently has arisen that takes issue with the validity of this conclusion based upon the statistical analysis of relative timing. Gentner (1982; 1985) argued that the invariance seen for relative time across the wide variety of tasks previously mentioned is not as robust as first thought due primarily to improper statistical techniques used to describe the data. To test this concern, Gentner (1985) adopted a statistical test for the multiplicative rate parameter that has been associated with the generalized motor program by various researchers.

Gentner (1985) argued that the weakness existing in the previous literature used to support the invariance of relative timing concept is due to the data being averaged over instances and subjects. Invariant relative timing, as a multiplicative rate parameter, should hold for all individual sequences, but may not hold in cases where data are averaged without considering individual performances. Therefore, Gentner proposed that individual data be used to test the linearity of the multiplicative rate parameter through a linear regression technique where individual components of a movement sequence are regressed against the total duration of movement time. If relative timing is an invariant characteristic of the generalized motor program, as defined by Schmidt (1982), then each individual's performance should reflect a regression line with a slope equal to zero for each component of the action sequence.

To test this hypothesis, Gentner reanalyzed data from several published works that have claimed support for relative timing invariances (e.g., Armstrong, 1971; Summers, 1976; Shapiro, 1978; Carter & Shapiro, 1984). When these data were reanalyzed from an individual regression approach, the results no longer supported relative timing as an invariant characteristic, as very few regression lines had slopes equal to zero. In fact, only human locomotion produced timing sequences that remained proportional when gait was speeded up or slowed down (Shapiro, Zernicke, Gregor, & Distal, 1981).

Two concerns, then, point to the need for additional study of relative timing as an invariant feature of the generalized motor program. First, previous investigations have been limited to manipulating the overall speed parameter of the task. However, if relative timing is invariant, then varying any of the hypothesized parameters (e.g., movement size, muscle selection or direction) should not influence the relative timing characteristics of the response. Second, Gentner's re-analysis of past investigations argues for the need to accomodate the methodological problem of using averaged data to predict timing invariances that are specific to individual performances.

Accordingly, it is the focus of this investigation to provide a series of dimensional and geometrical manipulations of a well-practiced movement response pattern to determine the nature of phasing as an invariant property of the generalized motor program. Of particular interest were the dimensional, spatial, directional, and muscle selection parameters related to producing a sequential movement pattern. If relative time is an invariant property of a generalized motor program, then temporal patterns of responding that were established during training should remain consistent when these parameters are varied during transfer. To test these predictions a series of four experiments were developed to systematically manipulate these parameter variables. Collectively these systematic manipulations provide a basis for addressing the robustness of the invariant characteristics of a generalized motor program and provide additional information about the features of movements which seem to be easily modified.

Experiment 1

It was the goal of the first experiment to determine if the timing structure of a well practiced three-component aiming response remains the same or varies when the size of the response (metrical components) as well as the geometrical properties of a task are manipulated for a transfer response. To test the importance of geometrical characteristics in programmed movement selection, individuals were trained to perform the three-component movement task and then transferred to a task having either identical or dissimilar geometrical properties. Manipulation of the dimensional properties was undertaken by requiring performance on a new task which, although geometrically similar was dimensionally dissimilar to the training task by being 50% larger than the training task. If topological similarities identify a common underlying motor program, as predicted by Bernstein (1967), then relative timing should remain constant when subjects are transferred to a task that has similar geometrical yet new dimensional characteristics. On the other hand, transferring to a task that differs in its geometrical characteristics while maintaining its dimensional characteristics should produce changes in relative timing.

Method

Subjects

Twenty-four undergraduate students, 7 males and 17 females, from Louisiana State University volunteered to participate as subjects. All subjects were recruited from undergraduate psychology classes and received course credit for their participation. Subjects were right hand dominant and naive to the experimental task.

Apparatus and Tasks

A response board (41 cm by 55 cm) on which was mounted a start switch, a 1 volt light emitting diode (led) which served as the stimulus light, and three movement target switches measuring rectangularly 10 x 5 mm were used to structure the movement task. The training task required individuals to perform a three-segment reaction time/movement time task. The respective amplitudes of each segment were 15 cm, 21.5 cm, and 24 cm long. The targets were positioned so that the angle of displacement varied for each segment. Movement segment 1 was performed at a 40° angle, movement segment 2 at a 90° angle, and movement segment 3 at a 30° angle of displacement. An illustration of the training task appears in Figure 1.

Insert Figure 1 About Here.

Two additional response boards were used as the transfer tasks. The targets for the geometrically-similar task were positioned at the same movement segment angles as the training task, allowing a spatially similar transfer condition. However, the movement dimensions for each segment were extended so that a 50% increase in each movement component's amplitude was established. The resulting dimensions were 22.5, 32.25, and 36 cm, respectively, for the three movement components.

The targets for the geometrically dissimilar task were positioned along a straight line (180°). Subjects performed this dimensionally similar but geometrically-dissimilar task by performing an aimed movement away from the midline of the body. Movement segment amplitudes were sequentially arranged such that segments 1, 2, and 3 were equal to the amplitudes used previously on the training trials.

An Apple II+ computer was used to control the experimental sequence, calculations of response times, intertrial intervals of 5 s in duration, a 70 ms warning buzzer, a fixed foreperiod of 1 s and the onset of the stimulus light. At the completion of each day's session the individual's data were stored for further analyses.

Procedures

The goal of the aiming task was for subjects to strike the required targets as rapidly as possible with a hand-held stylus. Following each trial, knowledge of results (KR) about the individual's reaction time (RT) and total movement time (MT) was presented on the monitor screen. Subjects were informed in advance that due to the nature of the task, if their error rate (missed targets) exceeded 10% of their total trials for any given day they would be dismissed from the experiment[1]

All subjects performed 100 trials on each day of the two day experimental session. A 2.5 minute break was given at the end of each 50 trial period. Day 1 was considered to be practice. On Day 2, 50 trials were performed on the training task. Following these trials subjects were transfered to either a geometrically-similar or a geometrically-dissimilar condition. Individuals (n = 12) were randomly assigned to each transfer condition. Subjects were instructed that the goal of the transfer task was identical to the training task and that they should attempt to strike the required target positions as rapidly as possible.

Analysis Procedures

Proportion of time for each of the three movement segments was calculated as MT_i/Total MT * 100 for each trial, where MT equals the MT for each of the three individual movement components. These three proportions were used as indicators of the relative time allocated to each movement segment. Trials were blocked (i.e., 10 trials equal 1 block) and averaged to form the dependent measures for the MANOVA analysis. In order to determine the nature of change occurring due to the transfer tasks, a repeated measures analysis was performed on the total MT, RT, and proportion of time for each segment variable. A 2 transfer condition x 2 treatment x 5 blocks with repeated measures on the last two factors multivariate anlaysis of variance was performed. The transfer condition referred to the type of transfer task the individual performed, whereas the treatment factor involved a comparison of performance on training and transfer blocks of trials. All post hoc analyses were performed using ANOVA procedures and a .05 level of significance was set *a priori* for all effects. All ANOVA *F* values can be found in Appendix C.

Of particular interest within the MANOVA effects are the treatment main effect and the treatment by transfer condition interaction. The significance of this main effect in combination with this interaction, provides a basis for determining training to transfer change or lack of change for each transfer condition manipulation. For example, a treatment main effect would reveal training to transfer differences averaged across both transfer conditions. Therefore, the significance or lack of significance of the transfer condition by treatment interaction would reveal if the training to transfer effects are specific to one transfer condition manipulation or characteristic of both transfer condition manipulations.

A second set of analyses, in accordance with Gentner's (1985) proposed test for a generalized motor program with a multiplicative rate parameter, was performed on the proportion of time for each movement segment for every individual. The first 10 trials of the training task were discarded in order to prevent an expected warm-up decrement effect from biasing the regression analyses. The results from the series of regressions are summarized and presented by transfer condition and movement segment proportion (see Appendix E). If an individual varied the proportion of time for any movement segment then the linear slope of the regression line would not be equal to zero.

In order to make comparisons across all transfer condition manipulations, ratios of the proportions representing each movement segment were established. The purpose of these ratios were to provide a non-biased estimate of the timing sequence of the various transfer parameter manipulations. It was of interest to determine if the temporal patterns established by subjects were based solely upon movement segment dimensions. Therefore, the temporal phasing patterns were established for the training task based upon the movement amplitudes of the individual movement segments: segment 1/segment 1; segment 2/segment 1; segment 3/segment 1.

By using a similar formula, based upon the mean proportion of time for each movement segment for training and transfer conditions (e.g., proportion 1/proportion 1; proportion 2/proportion 1; proportion 3/proportion 1), timing characterstics were established for each transfer condition - training/transfer combination. The transfer ratio for proportion 1 was adjusted based upon the ratio for proportion 1 on the training blocks. These ratios, labelled proportion of time ratios, permit an examination of the data among transfer conditions and experiments in terms of a descriptive representation of the three-component movement segment timing structure (see Table 1).

Insert Table 1 About Here.

Results

MANOVA Analysis

The repeated measures MANOVA revealed a main effect for treatment $F(5, 18) = 29.99$. A block within treatment effect, $F(32, 704) = 3.19$ was noted. A transfer condition by treatment interaction $F(5, 18) = 3.02$ was also significant. Contrasts performed in order to determine the difference within the blocks of trials for the transfer condition revealed that the first block of transfer trials were different from the remaining four blocks of trials, $F(5, 172) = 3.85$. No other effects were noted for Experiment 1.

Total Movement Time

The main effect for treatment, $F(1, 22) = 167.95$, for total MT revealed that the transfer task condition (M = 1177 ms, sd = 130 ms) was slower than the training task (M = 1016 ms, sd = 125 ms). The block within treatment effect, $F(8, 176) = 4.19$, indicated that decreases in total MT continued during the five blocks of transfer (about 60 ms) as well as the five blocks of trials on the training task (approximately 30 ms). Contrasts of transfer block performance $F(1, 8) = 14.93$, indicated that block one of transfer (M = 1216 ms, sd = 123 ms) was slower than the remaining blocks of transfer performance (M = 1166 ms, sd = 120 ms). The transfer condition by treatment interaction $F(1, 22) = 12.58$, revealed that although the training MT performances were similar for both transfer conditions, the similar-geometrical transfer condition had larger increases in MT on the transfer task (M = 220 ms, sd = 110 ms) than the dissimilar-geometrical transfer condition (_M_ = 124 ms, sd = 131 ms, see Figure 2).

Insert Figure 2 About Here.

Reaction Time

The similar-geometrical transfer condition revealed constant performance for RT during training (_M_ = 276 ms) and transfer (_M_ = 275 ms) blocks. The dissimilar-geometrical transfer also exhibited similar RTs during training blocks (_M_ = 275 ms) and transfer blocks (_M_ = 273 ms). Post hoc analyses revealed that no effects for RT as a dependent measure were significant.

Relative Time

Proportion 1. Proportion of time for movement segment one was faster during transfer (_M_ = 26.99%, sd = 2.66%) than during training blocks (_M_ = 27.31%, sd = 2.73%). The treatment by transfer condition interaction was also nonsignificant, indicating that less time was spent on proportion of time for movement segment one on both transfer conditions during transfer performance (see Figure 3). No ANOVA effects were significant for movement segment one.

Insert Figure 3 About Here.

Regression analyses revealed that 5 of 12 individuals within the dissimilar-geometrical transfer condition and 7 of 12 individuals within the similar-geometrical transfer condition had regression slopes not equal to zero (see Appendix E, Table 30 and 31).

Proportion 2. Individuals spent more time on movememt proportion two during training blocks ($\underline{M}$ = 35.25%, sd = 2.24%) than transfer blocks ($\underline{M}$ = 34.87%, sd = 1.75%). Individuals performing within the dissimilar-geometrical transfer condition decreased the proportion of time for movement segment two when transferred from training ($\underline{M}$ = 35.67%, sd = 2.36%) to transfer blocks ($\underline{M}$ = 34.71%, sd = 1.56%). The similar-geometrical condition exhibited more stable performance on proportion of time for movement segment two. A comparison of these proportions reflected that subjects spent more time during training ($\underline{M}$ = 34.84%, sd = 2.12%) than transfer proportions ($\underline{M}$ = 35.03%, sd = 1.92%, see Figure 4). None of the effects for movement proportion two were significant.

Insert Figure 4 About Here.

Regression analyses indicated that this proportion was the most stable of all proportions with respect to the temporal sequencing of movement segment two. Five of 12 individuals within the similar-geometrical and 6 of 12 individuals within the dissimilar-geometrical transfer conditions altered their timing patterns which resulted in regression lines with slopes not equal to zero (see Appendix E, Tables 30 and 31).

Proportion 3. Proportion three revealed a significant effect for treatment, $\underline{F}(1, 22) = 7.06$. Less proportion of time was allocated to movement segment three during training ($\underline{M}$ = 37.49%, sd

= 1.9%) than transfer (M = 38.14%, sd = 1.8%). Contrasts performed on transfer, comparing block one with the remaining transfer blocks, indicated that block one (M = 38.55%, sd = 1.7%) was slower than blocks two through five of transfer (M = 38.05%, sd = 1.8%), $F(1, 8) = 5.39$. The lack of a significant effect for the transfer condition by treatment interaction revealed that similar increases in proportion of time were evident for both transfer conditions (about a 0.9% increase for the dissimilar-geometrical transfer as compared to a 0.45% increase for the similar-geometrical transfer condition, see Figure 5.

Insert Figure 5 About Here.

Proportion three was the most varied segment as indicated by the regression analyses. Tabulation revealed that 8 of 12 individuals within the dissimilar-geometrical transfer condition contrasted with 6 of 12 individuals within the similar-geometrical transfer condition altered their temporal sequence when transferred to the novel condition (see Appendix E, Tables 30 and 31).

Proportion of Time Ratios. The temporal ratios based on the amplitudes of the training task were computed and revealed that individuals responding as quickly as possible would be expected to generate a 1 : 1.43 : 1.57 temporal ratio of responding on the three movement segments. However, during training individuals who transferred to the similar-geometrical condition responded at a 1: 1.32 : 1.39 rate whereas individuals who transferred to the dissimilar-geometrical condition performed at a 1 : 1.26 : 1.35

temporal rate (see Table 1). When comparing the training patterns to those exhibited during transfer trials, the dissimilar-geometrical transfer condition displayed the most consistent temporal phasing characteristics. These individuals perfomed at a 1 : 1.28 : 1.35 temporal ratio, whereas the individuals within the similar-geometrical transfer condition exhibited greater changes in phasing characteristics and responded at a .98 : 1.28 : 1.44 temporal sequence on the transfer task.

Discussion

The original assumptions within this experiment predicted that the transfer condition which required performances on a larger but identical geometrical task should display similar phasing characteristics. It was also of interest to determine if the actual dimensions the limb was required to travel, played a role in the timing patterns of movement. It was predicted originally that movements which varied geometrically would be maintained in different movement classes (Bernstein, 1967). Therefore, as initially predicted the dissimilar-geometrical transfer condition should have exhibited a different temporal structure based upon the selection of a new generalized motor program. However, this experiment revealed that both transfer condition's temporal patterns for movement segments one and two were similar to the temporal patterns present during training. Since movement proportion three reflected changes in temporal responding between training and transfer for both conditions and since the regression results indicated that 20 of 24 individuals did not exhibit slopes that were equal to zero, relative time does not remain invariant.

Therefore, these results are in contradiction with the previous results that support the idea of relative time as an invariant characteristic for sequential hand movement tasks (Armstrong, 1971; Summers, 1976; Shapiro, 1978; Langley & Zelaznik, 1984). Yet these results do support Gentner's (1985) notion that relative time within the generalized motor program is not based upon a multiplicative rate parameter.

Although relative time does not remain invariant when geometrical or dimensional parameters are varied, it was surprising to find that subjects within the dissimilar-geometrical transfer condition performed with relatively small changes in proportion of time when transferred to the new task. These changes evident from the MANOVA analysis (see Figures 3, 4, and 5) as well as the regression analyses (i.e., individuals revealed slightly larger proportion of time changes for all movement segments when transferred to the dissimilar-geometrical condition, see Tables 30 and 31 for a comparison) for relative time, although larger, cannot entirely explain the similar temporal patterns used by the individuals in this transfer condition.

One explanation to consider, when examining the similarities seen between the proportion of time ratios for training and transfer for the dissimilar-geometrical transfer task can be expressed in terms of the kinematic properties. For example, Langley and Zelaznik (1984) had subjects perform a similar three-component aiming task and found that individuals tended to produce temporal patterns based upon the kinematics of the required response. If the nature of the dimensions of the dissimilar-geometrical transfer task constrained individuals to perform at certain temporal patterns then one would expect similar temporal phasing characteristics between the training and transfer task for this transfer condition. These results seem to support this idea since the temporal structure of the training and transfer tasks for the dissimilar-geometrical transfer condition were very similar (1 : 1.26 : 1.35 versus 1 : 1.28 : 1.39, respectively). Therefore the temporal similarity that was noted for the training task as compared to the geometrically dissimilar transfer condition may be due solely to the kinematic similarity of the two responses.

Experiment 2

In Experiment 1 the temporal patterns of responding did not remain consistent when the physical constraints of the task were increased 50% to form the similar-geometrical transfer condition. Since changing the amplitude of the movement influences task difficulty (Fitts, 1954), it is necessary to consider task difficulty as a factor influencing relative timing changes before a complete picture can be developed for considering geometrical and dimensional features in the generalized motor program.

Movements which are characterized by similar geometrical properties should be controlled by the same motor program (Bernstein, 1967). Therefore the physical characterstics of a task (e.g., target size and/or movement amplitude) should not alter the underlying programming structure of tasks that share similar geometrical characteristics. Experiment 1 manipulated the dimensional properties of the task while keeping the geometrical configuration constant. Although a difference in timing was evident for proportion three in Experiment 1, the change was nominal (aproximately .5% from training to transfer) for the similar-geometrical transfer condition. For this reason, it was necessary to examine more closely the effect of manipulating index of difficulty on transfer task performance.

The purpose of this experiment is to manipulate index of difficulty while keeping the geometrical components constant. From a generalized motor program point of view, relative timing should remain invariant across different task difficulty levels when movement geometrical characteristics are similar, providing additional support that geometrical characteristics are critical in motor program selection and that movement dimensions are easily modified.

Method

Subjects

Thirty-six undergraduate students, 10 males and 26 females, from Louisiana State University volunteered to participate in this experiment for psychology and physical education course credit. All of the subjects were right hand dominant and naive to the experimental task.

Apparatus

The training apparatus is identical to the one used in Experiment 1 with the exception that three 1.5 cm circular disks were fixed to each target switch to insure proper levels of task difficulty. Three transfer tasks were employed. All transfer tasks shared the spatial/angular properties of the training task. Index of difficulty (ID) levels were calculated for all tasks using Fitts'

(1954) formula: log (2A/W). The index of difficulty ratios for each component of the training task were 4.32 ID for segment one, a 4.63 ID for segment two, and 5.00 ID for segment three.

The first transfer condition manipulated target size and movment amplitude to vary the task while achieving identical indexes of difficulty for each component segment established by the training board. Target size was increased from 1.5 cm to 2.0 cm in diameter. Movement amplitude was also increased such that the segment distances were 20 cm, 24.7 cm, and 32 cm, respectively.

In the remaining two transfer conditions the difficulty level of the original training task was decreased. However, difficulty levels of these two new transfer tasks were identical to each other. The first of these two transfer tasks increased the target size from 1.5 cm to 2.5 cm in diameter. The movement amplitudes remained unchanged as compared to the training task. The second transfer condition held target size constant (1.5 cm) while using new distances. These new distances were 9 cm, 12.6 cm, and 14.6 cm, respectively for the three movement components. The ID levels for these two conditions and were 3.58, 4.07, and 4.26 for the three component parts, respectively.

Procedures

The procedures for this experiment are identical to those used in Experiment 1. Individuals (n=12) were randomly assigned to one of the three transfer task conditions on the second day of the experimental session.

Results

MANOVA Analysis

A 3 transfer condition x 2 treatment x 5 blocks multivariate analysis of variance with repeated measures on the last 2 factors was performed. A treatment main effect, $F(5, 29) = 15.43$, was noted. The block within treatment effect, $F(40, 1136) = 3.20$, was also significant. Contrasts for block 1 of transfer as compared to the remaining blocks of transfer, indicated a significant effect, $F(5, 260) = 6.59$. A treatment by transfer condition interaction, $F(10, 60) = 5.82$, also was significant. No other MANOVA effects were significant.

Total Movement Time

ANOVA follow-ups revealed that total MT was faster during transfer (M = 815 ms, sd = 108 ms) than training (M = 895 ms, sd = 115 ms), $F(1, 22) = 68.82$. The block within treatment effect revealed that total MT block scores decreased across the training (about 41 ms) and transfer (about 35 ms) blocks, $F(8, 264) = 8.00$. Contrasts for block 1 of training compared to the remaining transfer blocks revealed that block one of transfer was slower for total MT when compared to the final four blocks of transfer, $F(1, 8) = 26.64$. The transfer condition by treatment interaction revealed similar MTs for all three transfer conditions on the training task, on the decreased ID transfer conditions subjects responded faster (about 200 ms) than training performances. In contrast subjects in the same ID transfer condition executed transfer trials approximately 50 ms slower than training performance, $F(2, 33) = 31.72$, (see Figure 6).

Insert Figure 6 About Here.

Reaction Time

Post hoc analysis of RT revealed a treatment main effect, $\underline{F}(1, 33) = 23.73$. RT was faster during transfer ($\underline{M}$ = 250 ms, sd = 31 ms) than training ($\underline{M}$ = 258 ms, sd = 31 ms). A block within treatment effect revealed that RT decreased across the five blocks within training (about 13 ms) and transfer (about 8 ms) conditions, $\underline{F}(8, 244) = 7.40$. Contrasts for the transfer condition revealed that block one RTs were slower than the remaining blocks of transfer RTs, $\underline{F}(1, 8) = 7.01$. Lack of a significant transfer condition by treatment interaction reflected the small RT changes during all transfer conditions, about 4 ms for the same ID transfer conditions and about 10 ms for both reduced ID transfer conditions.

A second post hoc anlysis was performed in order to determine if the RT main effect was due to the slower RT performance on the first block of trials for the training performance. When block one was deleted from the analysis, non-significant effects were noted for treatment, $\underline{F}(1, 33) = 2.52$ $\underline{p} > .12$, and the block within treatment effects, $\underline{F}(7, 14) = 1.57$ $\underline{p} > .15$) indicating that previous RT main effects were probably due to a warm-up decrement or other temporary effect.

Relative Time

Proportion 1. ANOVA follow-ups indicated that the proportion of time for movement segment one was less during the training task ($\underline{M}$ = 26.87%, sd = 2.12%) than the transfer task ($\underline{M}$ = 27.91%, sd =

2.20%). A block within treatment effect was also noted and revealed a gradual increase in the proportion of time during the training blocks (about .75%). Within the transfer blocks, a gradual decrease in proportion of time was exhibited across block performance (about .15%). The contrasts for block one versus the remaining four blocks of transfer was not significant. The lack of a significant treatment by transfer condition interaction revealed that all transfer conditions exhibited similar increases in movement segment one for transfer trials (see Figure 7).

Insert Figure 7 About Here.

Regression analysis for movement proportion one indicated that the same ID transfer condtion had 7 of 12 individuals with slopes not equal to zero. The decreased ID transfer conditions both showed changes in movement proportion for segment one for 8 of 12 individuals (see Appendix E, Tables 32, 33, and 34).

Proportion 2. Post hoc analysis indicated a treatment main effect, $\underline{F}(1, 33) = 25.60$. Proportion of time for movement segment two decreased from training ($\underline{M}$ = 36.25%, sd = 1.78%) to transfer (35.72%, sd = 1.94%) performance. The transfer condition by treatment interaction was also significant, $\underline{F}(2, 33) = 8.37$. A larger decrease in proportion of time for transfer as related to training was evident for the same ID task. In contrast, the reduced ID transfer conditions were similar to each other on training and transfer blocks of trials, (see Figure 8).

Insert Figure 8 About Here.

Regression analyses revealed that 6 of 12 individuals within the same ID transfer condition varied their proportion of time for movement segment two. Within the decreased ID transfer conditions 8 of 12 individuals had regression lines with slopes not equal to zero (see Appendix E, Table 32, 33, and 34).

Proportion 3. Follow-up anlysis for proportion of time for movement segment three revealed a treatment effect. Proportion of time on the training task ($\underline{M}$ = 36.93%, sd = 1.58%) was allotted more time than the transfer tasks ($\underline{M}$ = 36.39%, sd = 1.70%). The block within treatment effect indicated that a gradual decrease in proportion of time occurred during the training trials (about .50%). Very little change across blocks was noted during transfer (about .09%). The treatment by transfer interaction was also significant. The same ID transfer condition exhibited stable performance for treatment and transfer blocks whereas the decreased ID conditions, were similar to the same ID condition during training, yet decreased the time allocated to movement segment three during transfer (see Figure 9).

Insert Figure 9 About Here.

The regression analyses for proportion of time for movement segment three was the most stable proportion for the three movement segments. Two individuals within the same ID transfer condition, five individuals within the ID condition that manipulated movement distance, and seven individuals within the transfer condition that decreased difficulty and increased target size had regression lines with slopes not equal to zero (see Appendix E, Tables 32, 33, and 34).

Proportion of Time Ratios. The temporal ratios that were exhibited by individuals on the training and transfer tasks were calculated and appear in Table 1. All transfer conditions performed movement segment one more slowly during transfer. The proportion of time allocated to segments two and three decreased for all conditions. The individuals in the condition who performed the novel task in shorter amplitudes performed the final movement segment faster than segment two of the transfer response.

Discussion

The purpose of this experiment was to investigate the influence of index of difficulty (ID) manipulations on the phasing characteristics of a trained three-component movement response. Three transfer ID manipulations were used. The same ID condition employed larger targets and increased amplitude whereas the decreased ID tasks manipulated either target size or amplitude. In terms of the influence of ID on movement time (MT), results of these manipulations support the predictions of Fitt's law. The MTs for the same ID condition were slower but very similar to training task performance while the two similar decreased ID conditions revealed faster MTs than training, yet similar to each other on transfer performance.

In terms of relative timing characteristics, results of this experiment revealed that manipulations of task difficulty, in this case target size and amplitude, resulted in changes in the timing patterns of responding that subjects established during training. These results are similar to the changes seen in relative time in the geometrically similar transfer response in Experiment 1, where ID level was increased by increasing movement amplitude by 50%. Although these changes in both experiments were relatively small (1% or less for each individual segment), regression analyses in conjunction with the averaged data fail to support that ID manipulations are a parameter that is modified without altering the underlying timing invariances specific to a generalized motor program.

It is interesting to note that the two decreased ID transfer conditions as well as the same ID transfer condition exhibited similar changes in patterns of responding. These transfer conditions revealed that changes in relative time were due to decreased speed on movement segment one and increased speed on movement segments two and three of the transfer task. The same ID condition although similar to the decreased ID transfer conditions, revealed a larger decrease in time allotted to movement segment two than the decresed ID transfer condtions. In relation to the increased ID level task in Experiment 1, relative time was changed due to the an increase in speed on movement segments one and two, and a decrease in speed for movement segment three.

These results suggest that as the physical characteristics of the task vary, the latter movement segments of the response become easier for the individual to perform if the ID level decreases or remains constant. However, if task difficulty increases the final segment of the movement becomes more difficult and results in slower movement speed for the final segments, yet faster speed on initital movement components. Trade-offs in terms of gained movement speed for the final segments on tasks having equal or decreased difficulty levels influences individuals to restructure the phasing characteristics of the original task. Although the same ID condition increased movement speed on the final movement segment, the increases in speed were not as great as the easier task transfer conditions. This trend can be related to the similar-geometrical transfer condition in Experiment 1 where individuals who performed the more difficult task had increases in movement speed for the final segment of the movement response.

Although a secondary concern to this experiment, some investigator's have found RT increases with increased levels of difficulty (Henry & Rogers, 1960). Within this investigation only nominal decreases (about 10 ms) in RT as ID level decreased were found. This result in conjunction with a follow-up analysis to determine if RT differences were temporary and the finding of a lack of increase in RT for the increased ID level in the transfer task in Experiment 1 suggests that RT does not vary as a function of difficulty level. For this reason, RT is probably a function of movement complexity rather than index of difficulty levels.

Experiment 3

Bernstein (1967) has argued that direct mappings do not exist between the central commands and the specific effectors. Therefore, movements varying muscle selection should not alter the underlying temporal structure of the generalized motor program. Bernstein has also suggested that certain perceptual properties of a response are ignored by the motor system. Perception of movement or symmetry, as defined by Bernstein, corresponds to the orientation of a movement in space. For example, well learned movements like writing a a signature or playing a passage on the piano are performed with equal facility independently of the position of the hand or of the register on the piano. In this instance movements are carried out without regard to the physical constructs imposed by the task goal. For example, a beginning typist may be unaware of any typographical errors when their hands stray from the standard typing position.

Previous evidence has suggested that changes in limb during handwriting (Raibert, 1977) and wrist positioning tasks (Shapiro, 1977) do not modify the temporal representation of the movement response. For example, Raibert used the palindrome "Able was I ere I saw Elba" to determine changes in patterns of handwriting. This passage was performed using the right hand, the left hand, with a pen taped to the foot, and with a pen gripped in the teeth. The patterns of writing remained similar although the effectors used to produce the response were very different.

Changes in direction would also be considered to vary the muscle selction properties of the task. Subtle changes in directon should not alter the selection of the generalized motor program (Schmidt, 1982). However, reversals in direction have altered the phasing patterns characterized by similar movement responses (Quinn & Sherwood, 1983).

In order to test whether muscle selection properties as well as the symmetrical properties of an action are easily modified, a bilateral transfer paradigm was used. Previous experiments have suggested that relative time remains invariant when individuals are transferred from their dominant to non-dominant hand (Raibert, 1977; Shapiro, 1977). The perceptual properties of a task may also be manipulated by employing a bilateral transfer task. If limb and direction or direction components of the task are varied, then the symmetrical properties of the task have been manipulated such that the novel response is a mirror image of the training task. However, if the movement task is performed with the opposite limb, then the transfer condition is perceptually similar to the training task. Therefore, in this experiment the perceptual properties of the task as well as the muscle selection requirements of the novel transfer performance were manipulated. If muscle selection and symmetrical properties of the task are parameters that are easily modified within the motor program, then the timing characteristics exhibited during the training trials should carry over to transfer performance.

Method

Subjects

Thirty-six subjects, 6 males and 30 females, volunteered to participate in this experiment. Subjects were recruited from undergraduate physical education classes at Louisiana State University and received course credit for their participation. All subjects were right hand dominant and naive to the experimental task.

Apparatus

The training apparatus described in Experiment 1 was used to conduct the training trials for all individuals. This board also served as the transfer task for the opposite limb transfer condition. For the remaining two conditions a second response panel was constructed. All dimensions and geometrical properties were identical to the training task. The difference between this transfer task and the training task was that the target for the first and third movement segments were positioned on the left rather right side of the response board. Subjects performing in the opposite direction or opposite limb and direction transfer tasks were required to initiate the movement response on the first segment in a left rather than a right direction.

Procedures

The procedures in this experiment were identical to the procedures established in Experiment 1. Individuals (n=12) were randomly assigned to one of the three transfer conditions. The opposite direction transfer condtion involved performing the transfer trials by moving in a left direction. Transfer trials for the opposite limb transfer condition required subjects to move in the original training direction but to use the left limb. The opposite limb and direction transfer condition required subjects to change limb as well as direction.

Results

MANOVA Analysis

As in Experiment 2, a 3 transfer condition x 2 treatment x 5 block repeated measures analysis was performed. A main effect was noted for treatment, $F(5, 29) = 13.79$. A block within treatment effect, $F(40, 1136) = 3.24$, was also revealed. Contrasts between block one and the remaining blocks of the transfer trials, $F(5, 260) = 10.61$, was significant. A second contrast in order to determine if blocks two and three were different from four and five during transfer performance was also significant, $F(5, 260) = 3.06$. The transfer condition by treatment interaction, $F(10, 58) = 3.56$, was also significant. No other effects for Experiment 3 were significant.

Total Movement Time

Post hoc analysis of total MT revealed a treament effect, $F(1, 33) = 63.32$. Training blocks (M = 941 ms, sd = 123 ms) were performed more rapidly than transfer blocks (M = 1034 ms, sd = 126 ms). The block within treatment effect, $F(8, 244) = 10.97$, revealed that total MT decreased across training (about 40 ms) and transfer (about 58 ms) blocks. A contrast for the transfer blocks revealed that block one (M = 1077 ms) was slower than the remaining blocks of transfer (M = 1022 ms), $F(1, 8) = 43.41$. However, the second contrast effect, comparing blocks two and three and blocks four and five was non-significant for transfer performance. Movement time performance stabilized following the first block of transfer trials. The transfer condition by treatment interaction, $F(2, 33) = 13.99$, indicated that individuals who were required to perform the transfer task with the opposite limb had large increases in total MT as compared to the opposite direction group who performed as rapidly on the transfer as the training task (see Figure 10).

Insert Figure 10 About Here.

Reaction Time

A block within treatment effect was significant for RT and indicated a decrease in time across training (about 9 ms) and an increase in time during transfer (about 4 ms), $F(8, 244) = 2.32$. The block two and three contrast with block four and five effect was also significant, $F(1, 8) = 8.20$, and revealed that RT increased during the last two blocks of transfer performance (about 7 ms). Although the treatment by transfer condition was not significant, the opposite direction transfer condition RT on training blocks (M = 258 ms, sd = 30 ms) was faster than transfer blocks (M = 273 ms, sd = 33 ms). The opposite limb transfer condition revealed similar RTs for training (M = 264 ms) and transfer blocks (M = 262 ms). A slight increase in RT from training (M = 265 ms) to transfer blocks (M =270 ms) was evident for the opposite limb and direction transfer condition. All other post hoc analyses were non-significant.

Relative Time

Proportion 1. Proportion of time for movement segment one revealed that individuals increased the proportion of time allotted during training to transfer blocks for all transfer conditions. The opposite direction and the opposite limb and direction transfer conditions exhibited the greatest amount of change in relative timing from training (M = 27.50%, sd = 1.70% and M = 27.43%, sd = 3.31%, respectively) to transfer (M = 28.03%, sd = 2.55% and M = 27.91%, sd = 2.60%). Smaller changes in proportion of time were displayed by the opposite direction transfer condition for training (M = 27.42%, sd = 2.33%) and transfer (M = 27.70%, sd = 2.49%) blocks.

Insert Figure 11 About Here.

Regression analyses revealed that a total of 23 individuals across all transfer conditions on movement proportion one had regression slopes not equal to zero. The opposite direction transfer condition revealed that 9 of 12 individuals varied their temporal structure. Five of 12 individuals within the opposite limb transfer condition and 7 of 12 individuals within the opposite limb and direction transfer condition also had regression slopes not equal to zero (see Appendix E, Tables 35, 36, and 37).

Proportion 2. A treatment effect was evident for proportion of time for movement segment two, $F(1, 33) = 8.15$. The training blocks (M = 35.67%, sd = 1.68%) were allotted less proportion of time for movement segment two than the transfer blocks (M = 34.89%, sd = 1.71%). The block within treatment effect revealed that proportion of time was relatively stable for training, yet decreased about .5% during the transfer condition, $F(8, 244) = 2.23$. Although non-siginificant, the transfer condition by treatment interaction revealed decreases in proportion of time for movement segment two for the opposite direction, opposite limb, and opposite limb and direction from training (M = 35.55%, M = 35.61%, and M = 35.85%, respectively) to transfer blocks (M = 34.77%, M = 34.18%, and

35.72%, respectively). No other effects were significant for movement proportion two.

Insert Figure 12 About Here.

Regression analysis revealed that 22 individuals had regression slopes not equal to zero. Of these 8 of 12 within the opposite direction transfer and 10 of 12 within the opposite limb transfer condition varied their timing sequence as the task was manipulated. Only 4 of 12 individuals within the opposite limb and direction transfer condition had regression lines with slopes not equal to zero (see Appendix E, Tables 35, 36, and 37).

Proportion 3. A transfer condition by treatment interaction was the only effect significant for proportion of time for movement segment three, $F(2, 33) = 3.48$. Further inspection of this interaction revealed that.individuals within the opposite limb transfer condition allotted more time during transfer (M = 38.23%, sd = 1.49%) than during training (M = 36.98%, sd = 1.62%) as compared to individuals within the opposite direction or opposite limb and direction transfer conditions who performed similarly to each other on training (M = 37.05%, sd = 1.40% and M = 36.72%, sd = 2.24%, respectively) and transfer blocks (M = 37.22%, sd = 1.45% and M = 36.78%, sd = 1.80%, respectively, see Figure 13).

Insert Figure 13 About Here.

The regression analyses indicated that 24 of 36 individuals varied the temporal phasing of their responses when transferred to the novel task. Six individuals within the opposite direction transfer condition, 10 individuals within the opposite limb transfer condition, and eight individuals within the opposite limb and transfer condition exhibited regression lines with slopes not equal to zero (see Appendix E, Tables 35, 36 and 37).

Proportion of Time Ratios. The timing ratios exhibited by individuals for training and transfer blocks appear in Table 1. All individuals regardless of transfer condition performed slower on movement segment one. In contrast, temporal ratios were faster for all conditions on segment two. The opposite direction and opposite limb and direction transfer conditions continued to increase speed on movement segment three, resulting in smaller transfer proportions for the final movement segment. The opposite limb transfer condition, although similar to the other two transfer conditions for movement segments one and two, increased the amount of time allotted to movement segment three, resulting in a larger proportion of time allotted during transfer as related to training performance.

Discussion

Based upon the hypotheses for this experiment, it was predicted that changes in muscle selection and perceptual properties should not alter the relative timing structure exhibited by the generalized motor program. However, these results reveal that tasks involving the manipulation of these parameters by varying limb and direction components do not exhibit invariances for relative timing. These results do not support previous literature that has required individuals to respond with the opposite limb (Raibert, 1977; Shapiro, 1977). These data do, however, support other research work that has found that changes in direction (Quinn & Sherwood, 1983) as well as changes in the responding limb and direction combinations (Magill & Wood, 1986) has altered the relative time characteristics of the manipulated response.

The proportion of time ratios exhibited during transfer revealed that all transfer conditions had similar increases in time for movement segment one and decreases in time for movement segment two (see Table 1). However, for movement segment three, the opposite direction and opposite limb and direction transfer conditions continued to decrease speed whereas, opposite limb transfer condition allotted additional time for this segment. From a perceptual standpoint the two mirror image transfer tasks, (the opposite direction and opposite limb and direction conditions) displayed similar timing characteristics on transfer performance. However, the opposite limb transfer condition in which perceptual properties were not manipulated revealed proportion of time ratios most similar to the transfer conditions employed in Experiment 1, which increase the allotted proportion of time on the final segment of the movement response. These results suggest that manipulating the transfer task's perceptual properties or movement direction allows the individual to increase movement speed on the final two segments of the movement response.

Experiment 4

Experiment 3 indicated that the relative timing characteristics of a movement are varied when direction and the perceptual components of the task were manipulated. Direction changes according to Bernstein (1967) and Schmidt (1984) should not influence the timing characterstics of the motor program. If two movements are geometrically similar, then direction becomes a characteristic that is easily modified by the generalized motor program. In this experiment the direction of the task was manipulated without the perceptual components of the task changing. That is, movement direction was reversed so that the perceptual properties of the task were not altered.

A closer investigation of the task dimension properties was also investigated by varying the first and third components of the movement response. This is an extension of Experiment 1 which indicated that the kinematic properties of the transfer task may have determined the relative time characteristics exhibited by the dissimilar-geometrical transfer condition. In order to manipulate the kinematic properties of the transfer task, movement component one and movement component three were reversed. According to Bernstein (1967) and to Schmidt (1975) the kinematic properties of movements are considered to be easily modified parameters of the generalized motor program.

Method

Subjects

Twenty-four subjects, 7 males and 17 females, from undergraduate psychology classes at Louisiana State University volunteered to participate as subjects. Subjects received extra credit in undergraduate psychology classes for their participation. All subjects were right hand dominant and naive to the experimental task.

Apparatus

Both transfer condition tasks have geometrical properties identical to the training tasks. One transfer task also had identical dimensional characteristics of the training task (i.e., movement component one was 15 cm, movement component two was 22.5 cm, and movement component three was 24 cm long). The second transfer condition manipulated the first and third movement dimensions so that the first movement component in this transfer condition measured 24 cm followed by the second 21.5 cm movement. The third component's amplitude on this task was 15 cm long.

All other characterstics of the training and transfer tasks were identical to those described in Experiment 1.

Procedures

The procedures used in this experiment are identical to those previously employed. In order to vary the directional characteristics of the task, the transfer task boards were positioned so that subjects were required to perform the three component task in reverse. Subjects in both transfer conditions performed the new task in a direction toward the midline of the body.

The reverse direction transfer condition required subjects to perform an identical geometrical and dimensional task. The remaining transfer condition required similar geometrical but different kinematic properties when compared to the training task. For the reverse direction and dimension transfer condition the longest segment of the three component training sequence was executed first. The middle segment component was the same as the middle component of the training task. The last component to be executed in this transfer condition was identical to the first component on the training task.

Results

MANOVA Analysis

A 2 transfer condition x 2 treatment x 5 block repeated measures multivariate analysis of variance was performed. A main effect was noted for transfer condition, $F(5, 18) = 6.99$. The treatment main effect was also significant, $F(5, 18) = 21.29$. A block within treatment effect, $F(40, 752) = 3.19$, was also revealed. The contrast for block one versus the remaining blocks of transfer, $F(5, 260) = 9.49$. and for blocks two and three versus blocks four and five transfer was also significant, $F(5, 260) = 5.21$. The transfer condition by treatment interaction was significant, $F(5, 18) = 14.31$. No other effects were significant in this analysis.

Total Movement Time

The treatment main effect for total MT revealed that individuals performed faster during training (M = 1001 ms, sd = 167 ms) than transfer (M = 1037 ms, sd = 153 ms). A block within treatment effect for total MT revealed that speed decreased about 40 ms during the training blocks and about 86 ms across the transfer blocks. Two contrasts performed on the transfer trials revealed that individuals continued to decrease their response time across the transfer blocks. Block one was the slowest block of transfer (*M* = 1086 ms, sd = 157 ms), blocks two (*M* = 1047 ms, sd = 145 ms) and three (*M* = 1036 ms, sd = 145 ms) were faster than block one, yet slower than blocks four (*M* = 1009 ms, sd = 157 ms) and five (*M* = 1000 ms, sd = 162 ms). The transfer condition by treatment interaction revealed that the reverse direction and dimension condition performed faster than the reverse direction transfer condition during training but slower during transfer (about 60 ms). An illustration of this interaction appears in Figure 14.

Insert Figure 14 About Here.

Reaction Time

A block within treatment effect was noted for RT. RT decreased approximately 7 ms during training and 9 ms across the transfer blocks. The contrast effect for block one of transfer versus the remaining transfer blocks revealed that RT was slower for block one (*M* = 266 ms, sd = 29 ms) as compared to the remaining blocks of transfer (*M* = 258 ms, sd = 35 ms). Although no other RT effects were significant, the treatment by transfer interaction revealed an increase in RT from training (*M* = 248 ms) to transfer performance (*M* = 267 ms) for the reverse direction and dimension transfer condition. In contrast, the reverse direction transfer condition had faster RTs during transfer (*M* = 262 ms) than during training blocks (*M* = 252 ms). All other effects for RT were nonsignificant.

Relative Time

Proportion 1. A treatment effect for proportion one revealed that time allotted to proportion one was less during training (*M* = 27.43%, sd = 3.40%) than transfer blocks (*M* = 29.86%, sd = 2.25%), $F(1, 22) = 19.24$. The transfer condition by treatment interaction revealed relatively stable proportions for the reverse direction transfer condition, $F(1, 22) = 6.90$. The reverse direction and dimension transfer condition exhibited similar performance during training but displayed large increases in movement proportion time for segment one during transfer performance (see Figure 15).

Insert Figure 15 About Here.

Regression analyses indicated that 15 of 24 individuals varied their temporal structures for movement segment one. Five of 12 individuals within the reverse direction transfer condition and 10 of 12 individuals within the reverse direction and dimension transfer condition had regression lines with slopes not equal to zero (see Appendix E, Tables 38 and 39).

Proportion 2. Post hoc analyses revealed a treatment main effect for proportion of time for movement segment two, $F(1, 22) = 4.31$. Proportion of time analysis revealed that movement segment two was performed faster during training (*M* = 36.04%, sd = 2.24%) than transfer blocks (*M* = 37.03%, sd = 1.43%). The lack of the treatment by transfer condition interaction revealed that reverse direction transfer and the reverse direction and dimension transfer condition allotted less time to movement segment two during training

($\underline{M}$ = 35.99% and 36.08%, respectively) than transfer blocks ($\underline{M}$ = 36.39% and 37.67%, respectively; see Figure 16). No other effects were noted for proportion of time for movement segment two.

Insert Figure 16 About Here.

Regression analyses revealed that movement segment two was the most stable of the movement proportions with 10 of 24 individuals altering the temporal pattern of their response. Four individuals within the reverse direction transfer condition and six individuals within the reverse direction and dimension transfer condition exhibited regression lines with slopes not equal to zero (see Appendix E, Tables 38 and 39).

Proportion 3. A transfer condition main effect was evident for proportion three, $\underline{F}(1, 22) = 13.86$ and revealed that subjects in the reverse direction and dimension transfer condition ($\underline{M}$ = 33.74%, sd = 1.60%) allocated less time for movement segment three than the reverse direction transfer condition ($\underline{M}$ = 35.90%, sd = 2.69%). Post hoc analyses also revealed a treatment effect, $\underline{F}(1, 22) = 63.19$. Training performance ($\underline{M}$ = 36.54%, sd = 1.91%) on proportion of time for movement segment three was greater than transfer performance ($\underline{M}$ = 33.11%, sd = 1.93%). The contrast to test for a block one transfer difference was also noted for proportion of time for movement segment three, $\underline{F}(1, 8) = 5.06$. Results indicated that block one ($\underline{M}$ = 33.49%, sd = 1.77%) was allotted more time than the remaining blocks of transfer ($\underline{M}$ = 33.02%, sd = 1.97%). The transfer condition by treatment interaction was similar to the interaction noted for proportion of time for movement segment one, $\underline{F}(1, 22) = 22.67$. Performance was similar for both transfer conditions during training, however following transfer the reverse direction and dimension transfer condition decreased the amount of time they allotted to movement proportion three (see Figure 17).

Insert Figure 17 About Here.

Regression analyses revealed that 17 of 24 individuals within proportion of time for movement segment three had regression lines with slopes not equal to zero. Of these 17, 8 individuals within the reverse direction transfer condition and 9 within the reverse direction and dimension transfer condition varied the timing they had exhibited during performance on the training task (see Appendix E, Tables 38 and 39).

Proportion of Time Ratios. The proportion of time ratios for training and transfer appear in Table 1. Relative timing characteristics although similar during training were different during transfer performance. Subjects on both transfer conditions increased speed on movement segments two and three, and decreased speed on movement segment one. The reverse direction and dimension transfer condition's proprtion of time allocated to movement segment three was faster than movement segments one and two. The pattern of timing displayed by the reverse direction condition on the transfer trials was similar to the timing patterns exhibited in previous experiments.

Discussion

According to the concept of the generalized motor program, parameters like direction and kinematics should not alter the relative timing structure exhibited by the abstract program characteristics. However, these results suggest that changes in movement direction and task kinematics vary the relative timing associated with the generalized motor program. As such, these results replicate the results of direction changes exhibited in Experiment 3 and further support results reported by Quinn and Sherwood (1983) and by Magill and Wood (1986) who found similar changes in relative timing due to response direction alterations.

These data also provide evidence that the kinematic properties of the task are directly related to the proportion of time exhibited for each movement segment. Although, a one to one ratio between movement segment amplitude and proportion of time ratio was not evident (e.g., our data did not reveal a complete reversal for proportion of time ratios for segments one and three during transfer), the reduced movement amplitude for segment three and the increased movement amplitude for segment one during the reverse direction and dimension transfer condition did alter the training task proportions of time for these segments, inversely. That is, proportion of time for movement segment three decreased due to the shorter amplitude required for this movement component during transfer performance. These data support the results of Langley and Zelaznik (1984) and the results from our dissimilar geometrical transfer task in Experiment 1. These experiments indicate that the kinematic properties of movements are at least partially responsible for the observed relative timing patterns exhibited during performance.

Not only did the reverse direction and transfer condition display large increases in proportion of time for movement segments one and three, this condition also required more blocks of trials as compared to the reverse direction transfer condition. Movement time as well as RT measures continued to decrease across blocks of transfer trials. However, all proportions of time for the individual movement segments stabilized within the first block of transfer. This evidence provides additional support that the transfer task kinematics, although exhibiting consistent decreases in total MT and RT, are a determining factor for the relative timing invariances thought to be controlled by the generalized motor program.

In relation to the proportion of time ratios, the reverse direction and reversed direction and dimension transfer conditions had similar phasing characteristics for movement segment two (see Table 1). Individuals within both transfer conditions performed slightly faster on movement segment two. The reverse direction transfer condition was also similar to other transfer conditions in previous experiments in that increases in movement speed during transfer was due to the decreasing proportions of time allotted for movement segments two and three. From a comparison approach the reverse direction and dimension transfer condition did not exhibit performance similar to any previous transfer condition.

General Discussion

According to the current view of the generalized motor program (e.g., Pew, 1974; Schmidt, 1975; 1982), relative timing is an invariant characteristic of an abstract representation of action while specific features like overall duration, movement direction, and muscle selection, are considered to be variant parameters. These variant parameters can be readily modified to fit the demands of a specific response situation without altering the underlying structure of the relative timing. Therefore, the outward appearance of a movement response may vary without changing the underlying deep structure of the movement response. According to this generalized motor program concept, individuals who are well trained on a three-component movement task should display similar relative timing characteristics when transferred to a novel task that varies in terms of any parameter manipulations, such as the physical dimensions of the task, muscle selection, or the direction properties of novel task production.

Results of the present series of experiments failed to support this view that relative timing is an invariant characteristic of a generalized motor program. However, it is important to note that except for the reverse direction and dimension transfer condition, all of changes noted for relative timing, ranged in magnitude from .5 to 2% for any movement segment's proportion of time ratio. Although these variations are seemingly quite small (no more than 5 to 20 ms for each movement segment), current definitions of relative timing use a multiplicative rate parameter characteristic and therefore do not allow for any changes in relative timing characteristics across movements considered to be under the control of the same motor program. One possible direction to be taken then, would be to accomodate the present results in a revised version of what is meant by relative timing invariance as an invariant characteristic of a generalized motor program.

It was of particular concern that the small changes in relative time across the various experiments might be due to an individual's variability in motor output rather than a change within the central timing structure of the generalized motor program. For example, the average variability calculated for movement segment one during training and transfer trials for the reduced index of difficulty transfer conditions was 1.6% and 2%, respectively. However, analysis of variance procedures detected changes in relative timing between training and transfer trials for the reduced index of difficulty transfer condition for movement segment one to be less than 1%. Changes in timing structure are thought to be due to selecting a new generalized motor program. Perhaps timing structure variations are due to an individual's variability in motor output responding. Although current ideas of the generalized motor program with relative timing as an invariant characteristic do not take into account an variability in responding, two responses of the same action are never perfectly identical (Schmidt, 1985). For this reason we feel that the generalized motor program with a timing invariance should be revised in order to account for individual variability in movement responding.

Throughout these experiments the proportion of time ratio patterns varied according to the nature of the transfer task manipulation. However, one characteristic that was consistent for all transfer conditions, except those in Experiment 1, was that the time allotted to the first movement segment was longer during transfer performance. Another characteristic that was consistent across manipulations in transfer was that the proportion of time for movement segment two was allotted less time during transfer than training, except for individuals performing the geometrically dissimilar transfer condition performance. Most transfer conditions also exhibited increases in speed for movement segment three during transfer performance resulting in smaller proportions of time for the final movement segment. However, the opposite limb transfer condition and both transfer conditions in Experiment 1 had longer proportion of times for the third movement segment.

Each of these response characteristics occurred despite the fact that as the nature of the task was varied, the overall goal of the response remained consistent. That is, the movement goal across all training and task conditions was to perform the three-component movement response as rapidly and accurately as possible. It is possible, then, that in situations where movement speed increased over the last two segments, individuals became aware that by increasing speed on the final movement segments, total duration of time would be most affected. However, for tasks that were more difficult (increased dimension) or tasks that required a postural adjustment (the dissimilar-geometrical transfer condition required that individuals extend and reach 60 cm to strike the last target position) movement speed on component three was not as easy to reduce. Although this characteristic was also observed for the opposite limb transfer condition, it cannot be established from these experiments why this condition revealed this pattern of responding. It appears then, that specific task manipulations govern the strategies of the individuals within those conditions. If a task manipulation (e.g., the decreased index of difficulty transfer condition) is less difficult to perform, then increases in speed are generally seen in the final two movement components of the transfer response. However, as the difficulty level of the task increases, as seen in Experiment 1, individuals are not able of increasing speed on the final segment of the transfer task.

In a different light, several problems intuitively arise when inferences are drawn from data that have been averaged and discussed in terms of a phenomenon (in this case the nature of a generalized motor program) that is specific to individual performance. Although averaged data may be an accurate predictor of individual performances, in some cases actual individual performances may be masked. For this reason, in the situations where individual performance is crucial to the nature of the problem, group analyses may not be an appropriate technique (Gentner, 1985). On the other hand the alternative suggested by Gentner, regression analyses of individual data, may be too sensitive. Another problem is that regression is not an analysis procedure designed to handle data that are essentially in a multivariate framework (i.e., repeated trials and repeated segment proportions). Further the regression technique fails to account for an acceptable level of variance in these experiments. The percent of variance accounted for by the regression line for any individual were well under the 5% mark.

This troubling low amount of variance accounted for by Gentner's (1985) technique suggests that the data do not fit the model and that the regression technique may not be statistically valid. However, based on the statistical drawbacks of testing null effects an argument should be raised that a descriptive presentation of individual data in combination with the averaged analyses might be an acceptable solution to methodological problems.

From a theoretical standpoint, the generalized motor program is based upon the notion that motor performance is determined by a central control mechanism which specifies the outputs responsible for movement execution. This output generated by the generalized motor program is assumed to correspond directly to the timing structure of the observed behavior. Although the evidence from the present experiments do not support the relative timing invariance as a characteristic of a generalized motor program, in light of the overwhelming evidence for central representation of motor skills within the brain and spinal cord (Grillner, 1985), a generalized motor program is still a viable mechanism for control. What this means, then, is the basis for establishing relative timing as an invariant characteristic of a generalized motor program is not valid as presently stated.

In agreement with Schmidt (1985), who in a recent review of the generalized motor program and its invariances among skilled behaviors, stated that the relative timing approach in which temporal structure is scaled in proportion to MT is probably too simple. Primarily he bases this statement on the inability of relative time to remain invariant for single aiming tasks (Zelaznik

& Schmidt, 1983; Zelaznik, Schmidt, Gielen, & Milich, 1985), reanalysis of typing data by Gentner (1982; 1985), and the fact that intercepts in relation to EMG duration and overall MT are generally positive. If the scaling of events is nonlinear, then the simple oscillator models of control, like relative timing, in which all apects of a movement are sped up proportionally, will not be effective explanations for behavioral changes.

A likely alternative view is one suggested by Gentner (1985) that movement behaviors are probably based upon a composite model of control. The generalized motor program within the composite model of control serves as one mechanism among many overlapping control mechanisms. Within this composite model, control of timing could be based on any one of several levels of the perceptual-cognitive-motor system (Keele & Summers, 1976; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). As skill level of the performer increases the relative performance of control levels shift accordingly. Therefore, the timing of the response would not necessarily be based upon a simple oscillator mechanism as predicted by the current generalized motor program. Within the composite model, the timing of a skill could be based in accordance with skill level and environmental constraints. This could explain, for example, why relative timing remains invariant for some movements but not others. The need then, is to direct future research within this area is by studying actions performed under varying conditions and skill levels in order to identify the nature of control shifts within skilled performance.

Footnote

Three individuals within the four experiments were dismissed from the experiment due to more than a 10% error rate on Day 1 of training trials.

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Table 1

Proportion of Time Ratios for Training and Transfer Trials

	Training			Transfer		
	Segment					
Transfer Condition	1	2	3	1	2	3
Similar-Geometrical	1.00 :	1.32 :	1.39	0.98 :	1.29 :	1.44
Dissimilar-Geometrical	1.00 :	1.26 :	1.35	1.00 :	1.28 :	1.39
Same ID	1.00 :	1.34 :	1.36	1.10 :	1.25 :	1.32
Decreased ID and Dimension	1.00 :	1.36 :	1.40	1.10 :	1.31 :	1.30
Decreased ID/Increased Target	1.00 :	1.34 :	1.37	1.10 :	1.27 :	1.28
Opposite Limb	1.00 :	1.30 :	1.35	1.10 :	1.23 :	1.38
Opposite Direction	1.00 :	1.29 :	1.35	1.10 :	1.24 :	1.32
Opposite Limb and Direction	1.00 :	1.31 :	1.34	1.10 :	1.28 :	1.30
Reverse Direction	1.00 :	1.31 :	1.33	1.04 :	1.28 :	1.24
Reverse Direction/Dimension	1.00 :	1.30 :	1.33	1.13 :	1.20 :	0.98

Note. The proprtion of time ratios were based on the mean proportion of times for each movement segment and each transfer condition.

Figure Captions

Figure 1. A top view illustration of the geometrical configuration of the training apparatus.

Figure 2. The treatment by transfer condition interaction depicting changes in total movement time across training and transfer blocks for Experiment 1.

Figure 3. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment one across training and transfer blocks for Experiment 1.

Figure 4. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment two across training and transfer blocks for Experiment 1.

Figure 5. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment three across training and transfer blocks for Experiment 1.

Figure 6. The treatment by transfer condition interaction depicting changes in total movement time across training and transfer blocks for Experiment 2.

Figure 7. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment one across training and transfer blocks for Experiment 2.

Figure 8. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment two across training and transfer blocks for Experiment 2.

Figure 9. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment three across training and transfer blocks for Experiment 2.

Figure 10. The treatment by transfer condition interaction depicting changes in total movement time across training and transfer blocks for Experiment 3.

Figure 11. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment one across training and transfer blocks for Experiment 3.

Figure 12. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment two across training and transfer blocks for Experiment 3.

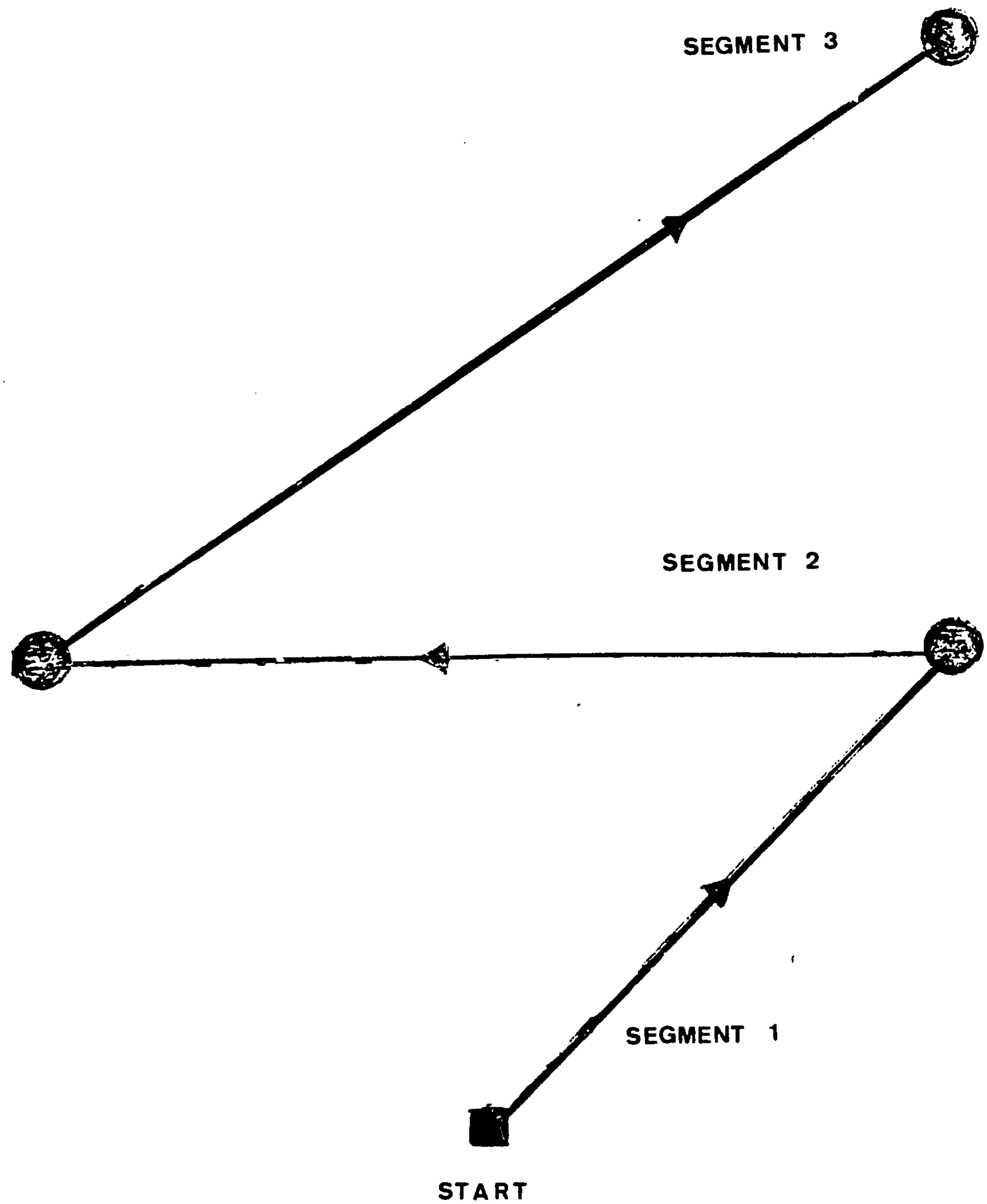
Figure 13. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment three across training and transfer blocks for Experiment 3.

Figure 14. The treatment by transfer condition interaction depicting changes in total movement time across training and transfer blocks for Experiment 4.

Figure 15. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment one across training and transfer blocks for Experiment 4.

Figure 16. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment two across training and transfer blocks for Experiment 4.

Figure 17. The treatment by transfer condition interaction depicting changes in proportion of time for movement segment three across training and transfer blocks for Experiment 4.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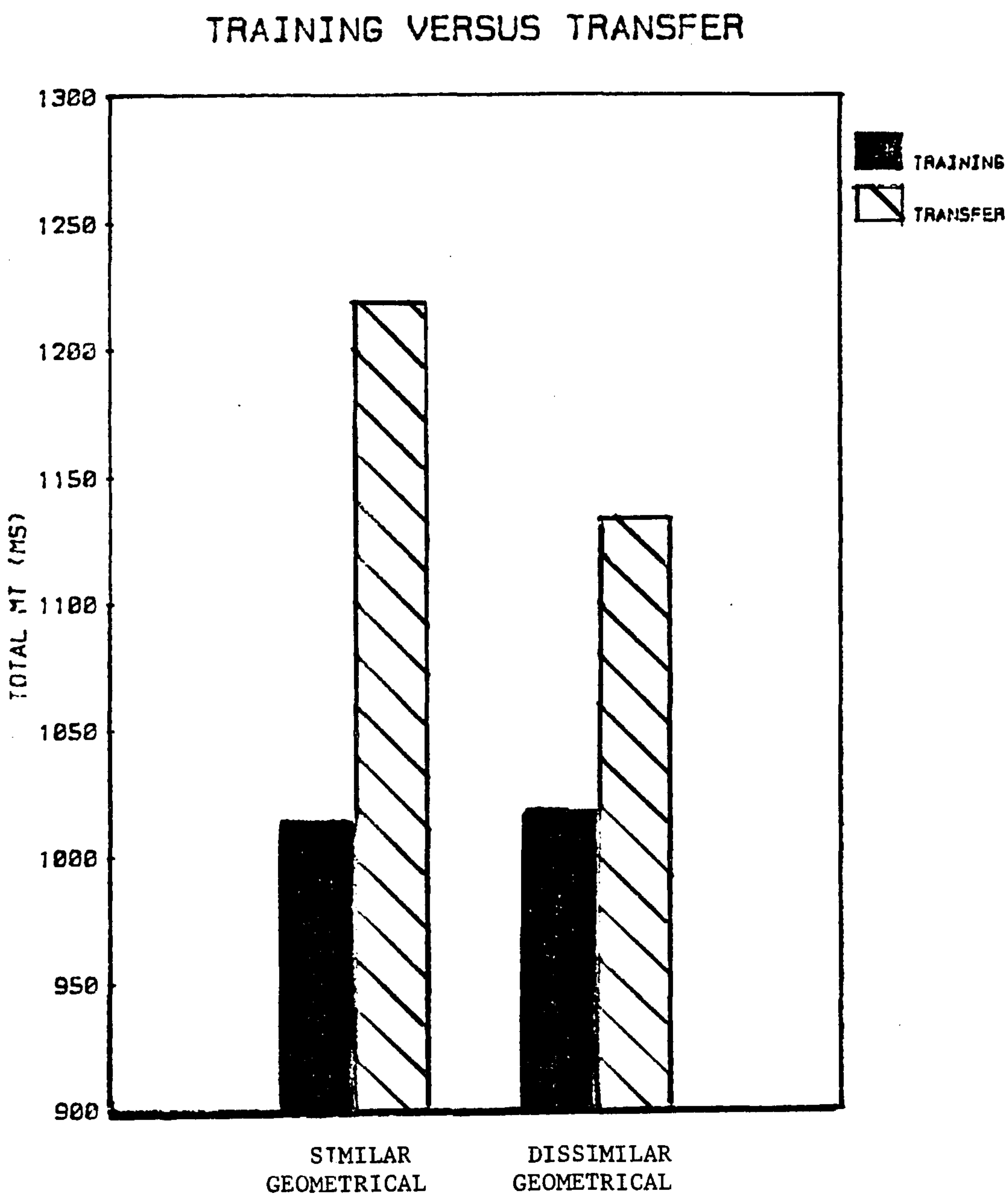
SEGMENT 2
SEGMENT 1
START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1300
1250
1200
1150
1100
1050
1000
950
900
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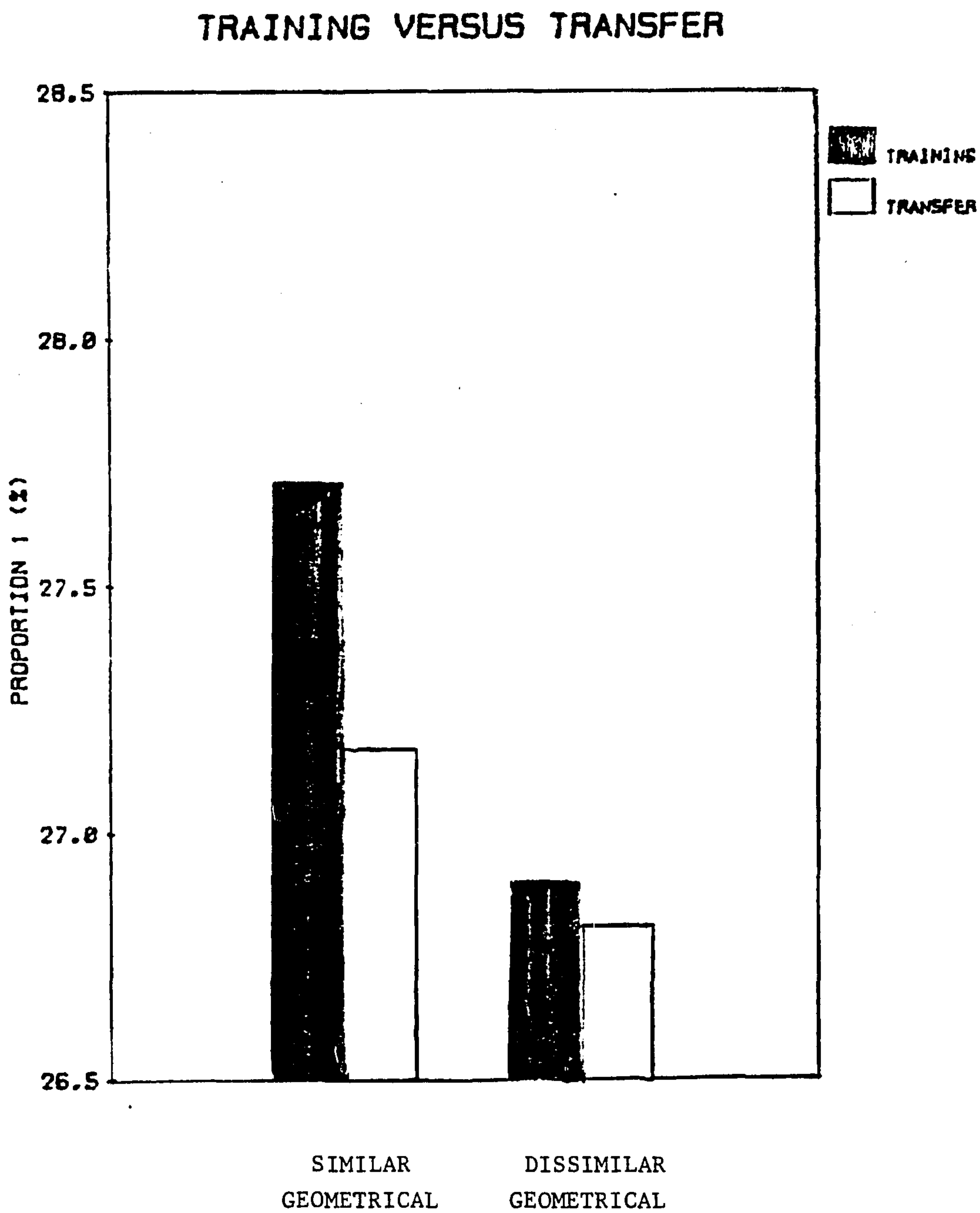
DISSIMILAR GEOMETRICAL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27.5
27.0
26.5
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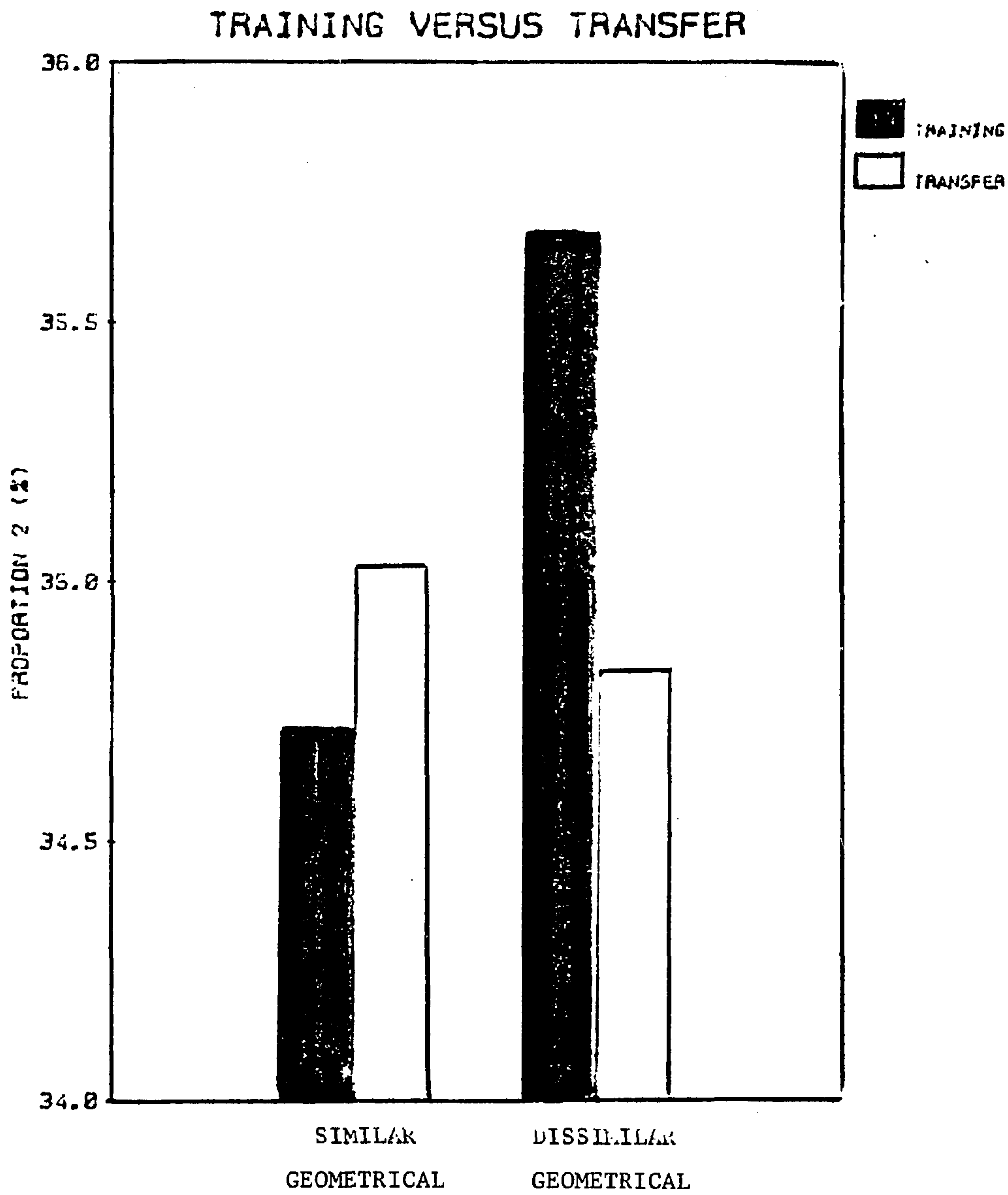
TRAINING
TRANSFER
SIMILAR GEOMETRICAL
DISSIMILAR GEOMETRICAL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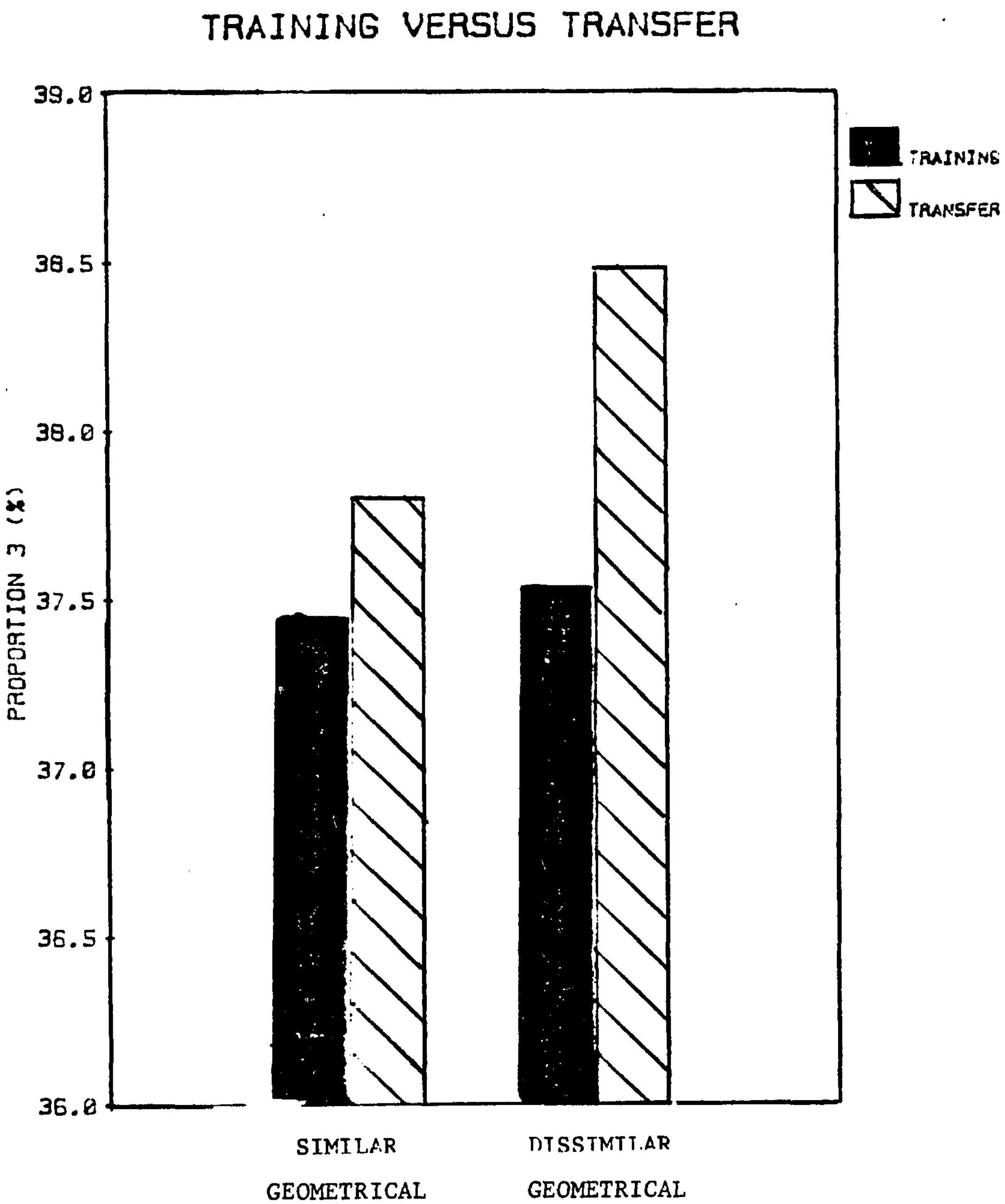
36.0
35.5
35.0
34.5
34.0
PROPORTION 2 (%)
TRAINING
TRANSFER
SIMILAR
GEOMETRICAL
DISSIMILAR
GEOMETRICAL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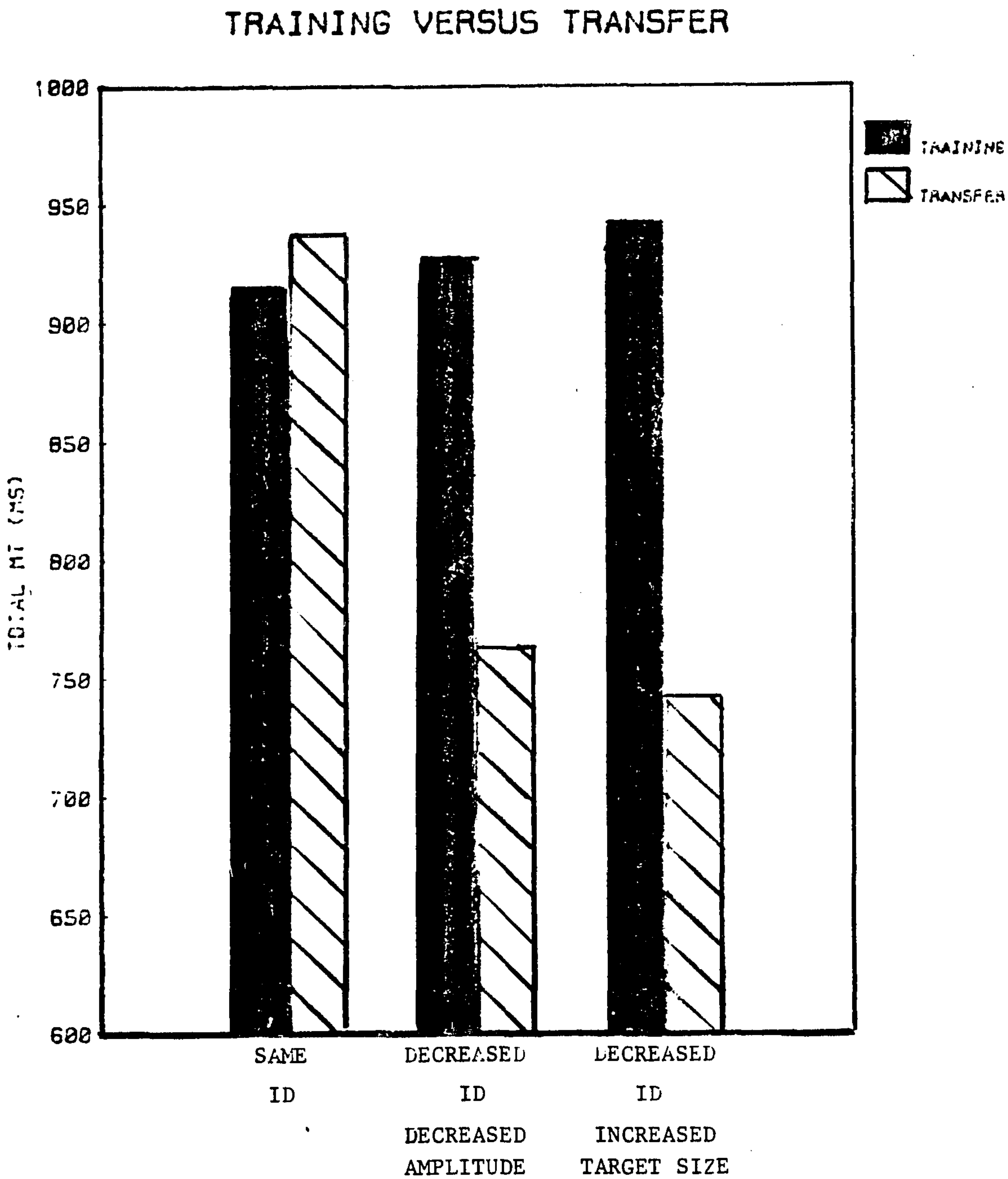
39.0
38.5
38.0
37.5
37.0
36.5
36.0
PROPORTION 3 (%)
TRAINING
TRANSFER
SIMILAR
GEOMETRICAL
DISSIMILAR
GEOMETRICAL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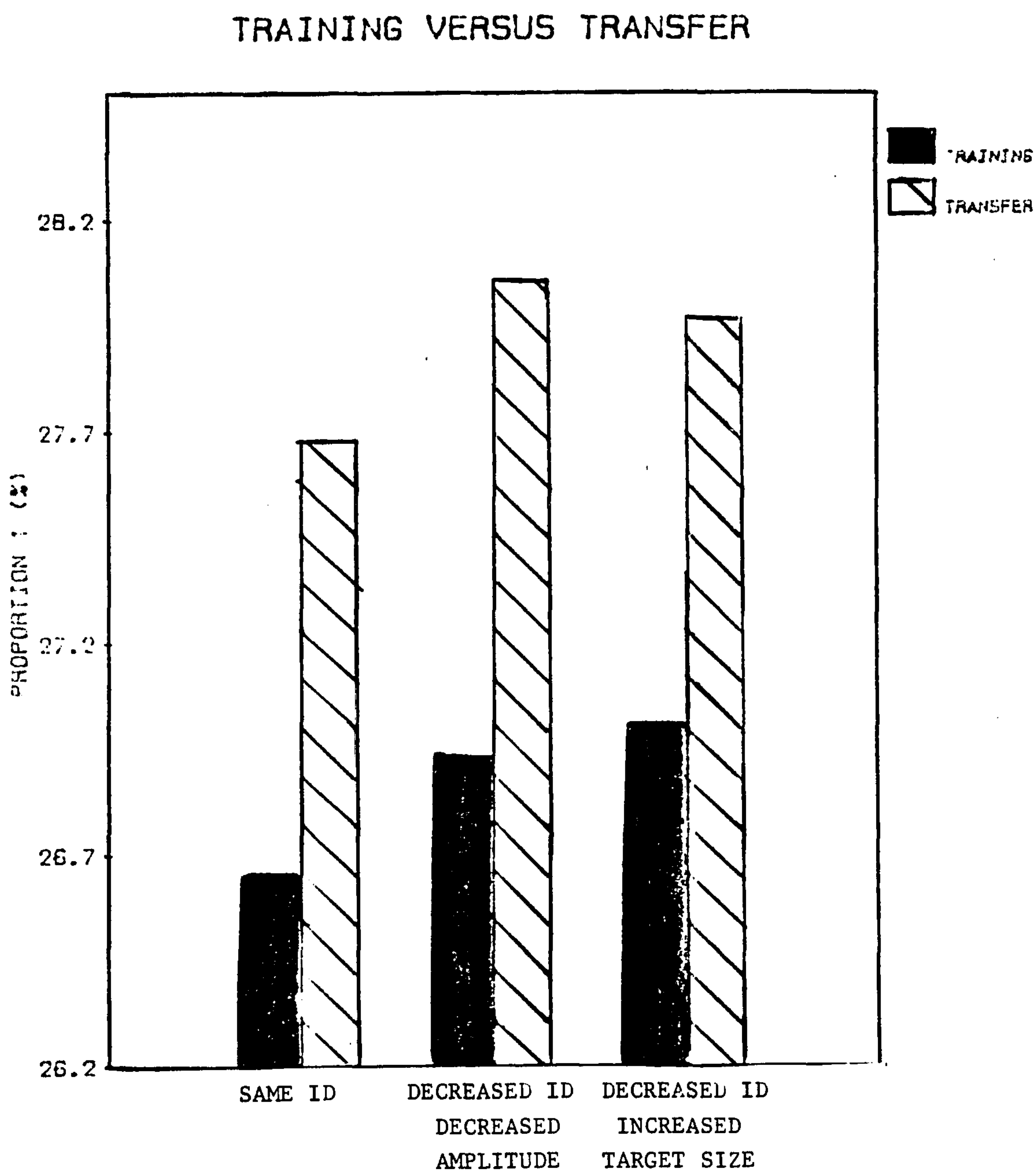
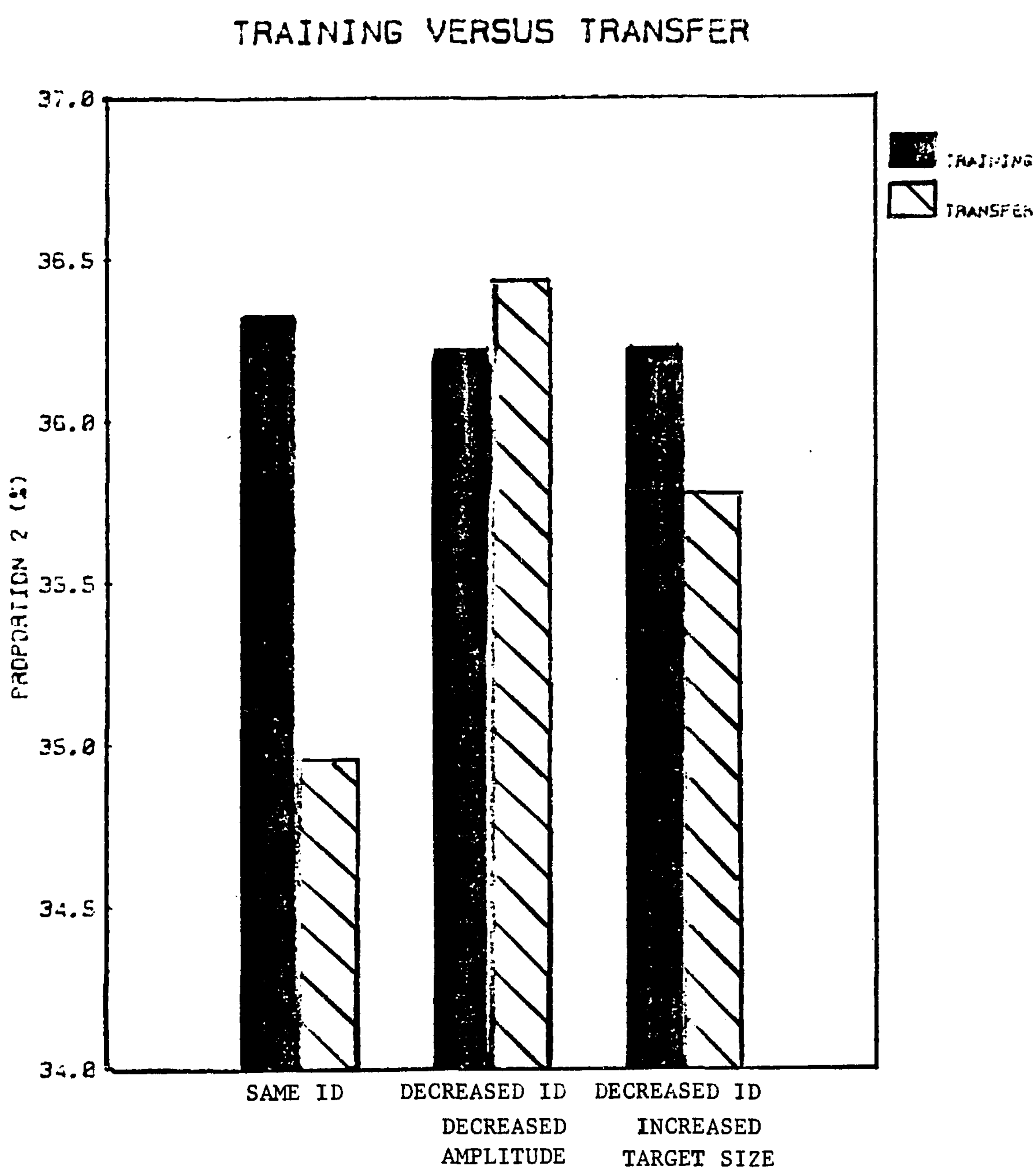
TOTAL MT (MS)
1000
950
900
850
800
750
700
650
600
TRAINING
TRANSFER
SAME
ID
DECREASED
ID
DECREASED
AMPLITUDE
DECREASED
ID
INCREASED
TARGET SIZE


TRAINING VERSUS TRANSFER
TRAINING
TRANSFER
28.2
27.7
27.2
26.7
26.2
PROPORTION : (%)
SAME ID
DECREASED ID DECREASED AMPLITUDE
DECREASED ID INCREASED TARGET SIZE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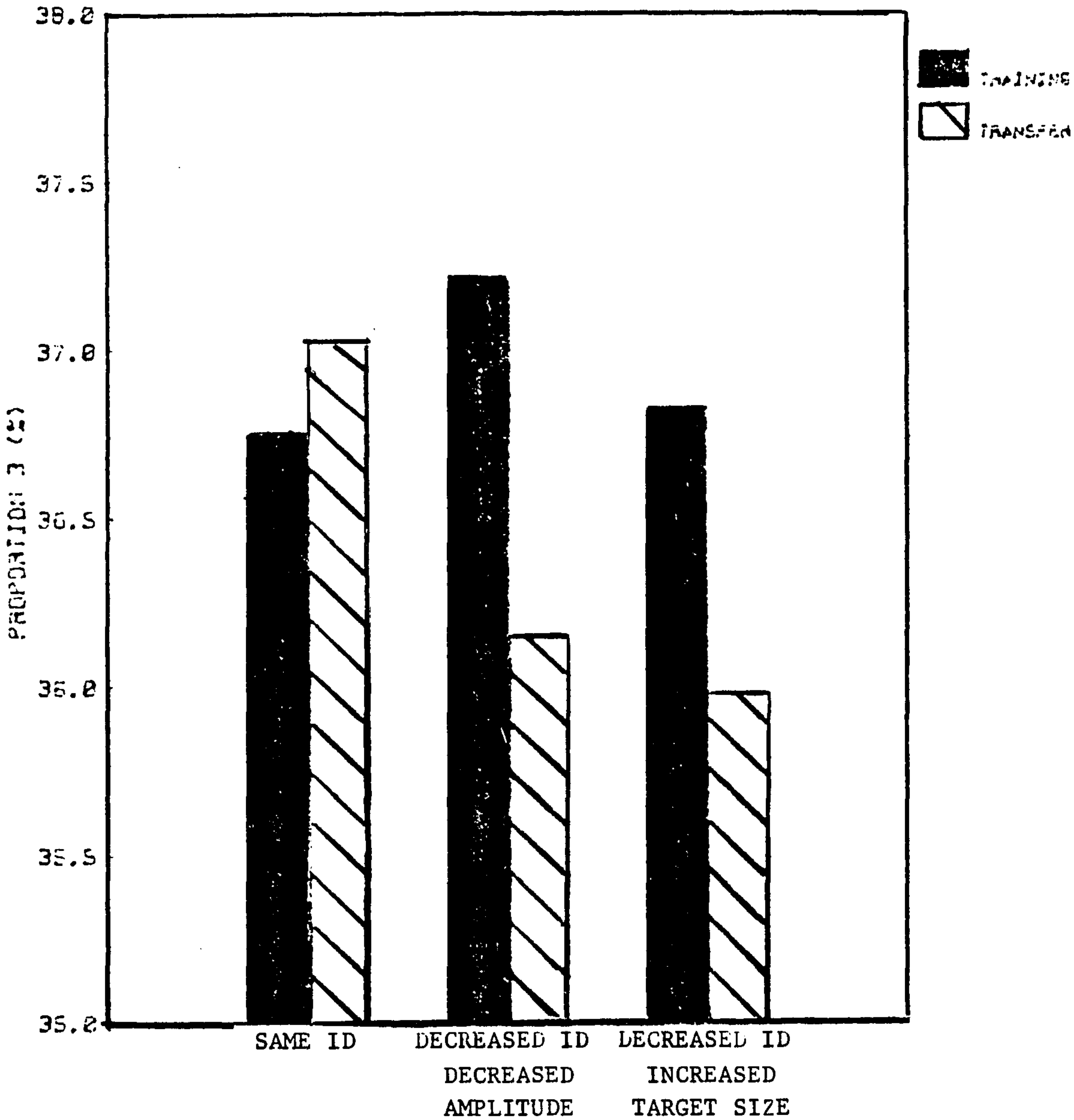
36.5
36.0
35.5
35.0
34.5
34.0
PROPORTION 2 (%)
TRAINING
TRANSFER
SAME ID
DECREASED ID
DECREASED
AMPLITUDE
DECREASED ID
INCREASED
TARGET SIZE

TRAINING VERSUS TRANSFER



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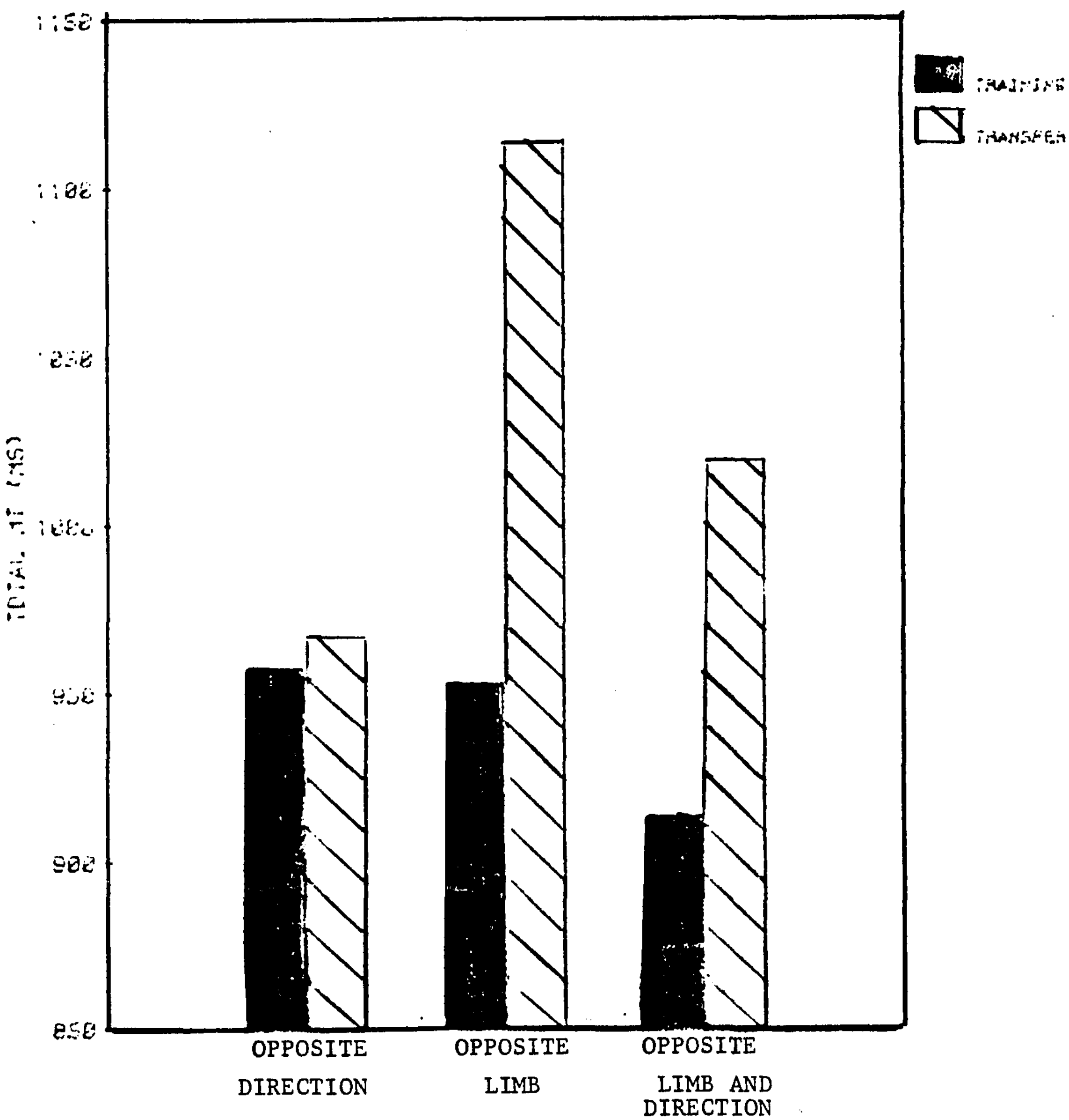

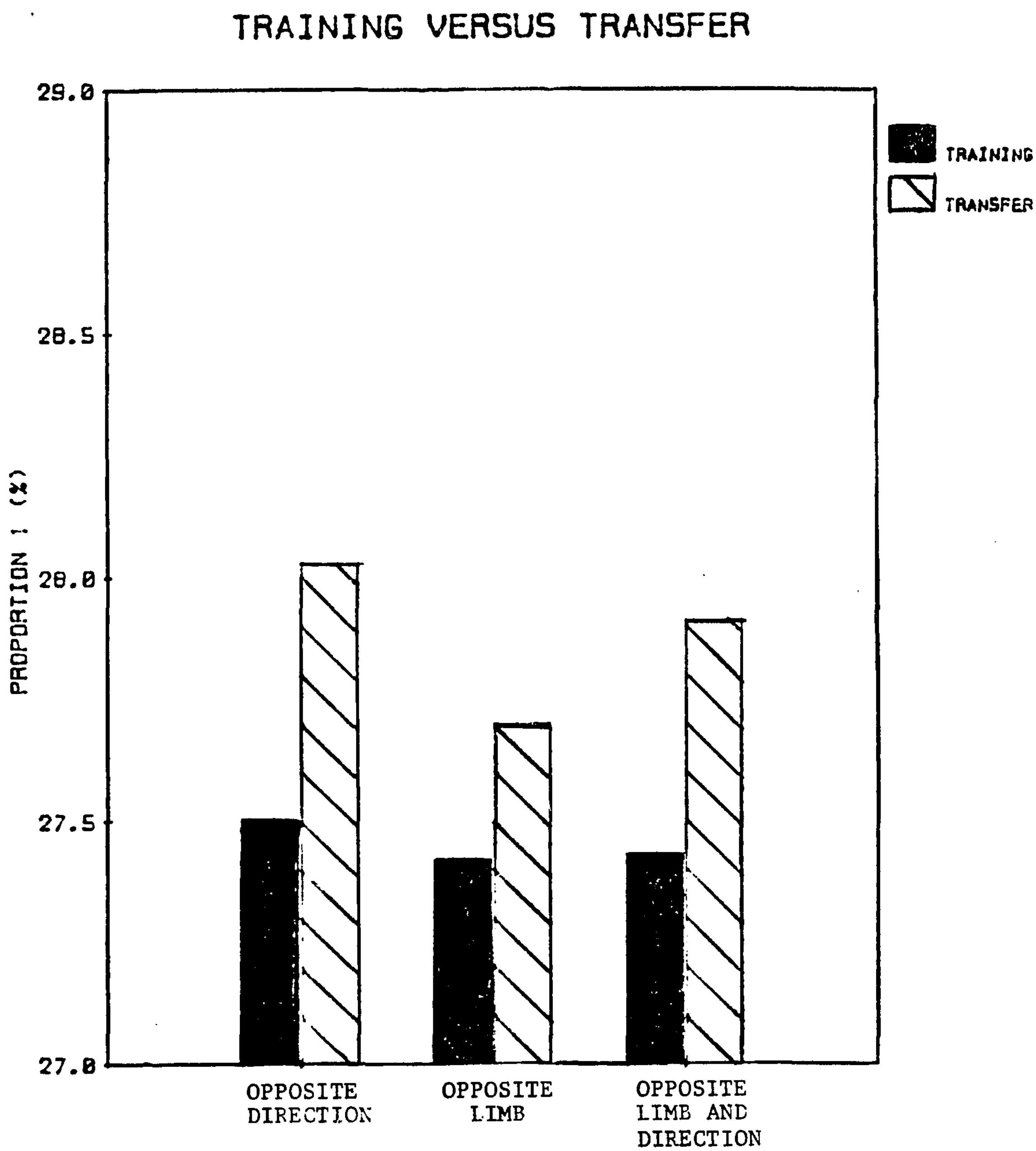
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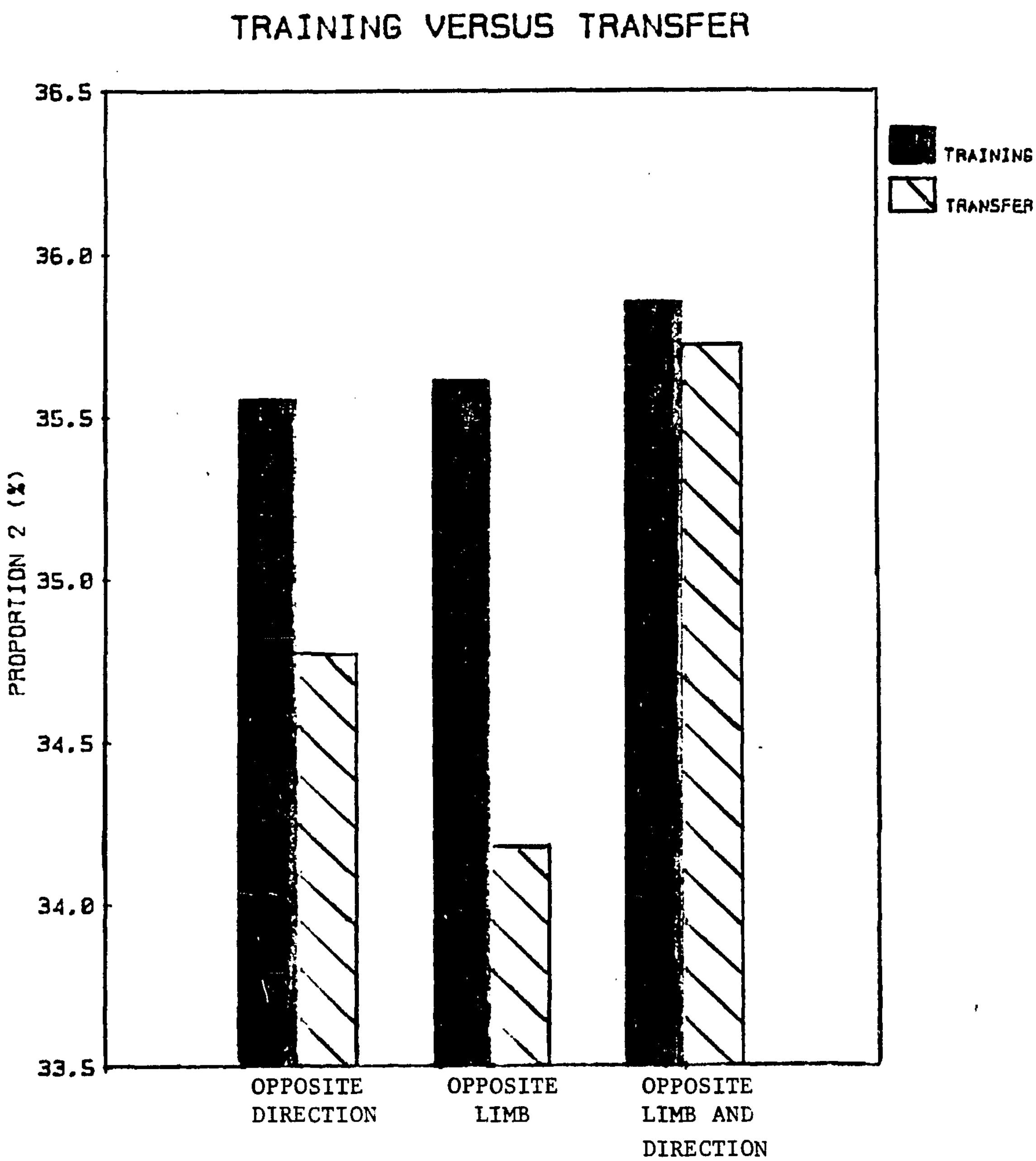
28.5
28.0
27.5
27.0
PROPORTION : (%)
TRAINING
TRANSFER
OPPOSITE DIRECTION
OPPOSITE LIMB
OPPOSITE LIMB AND DIRECTION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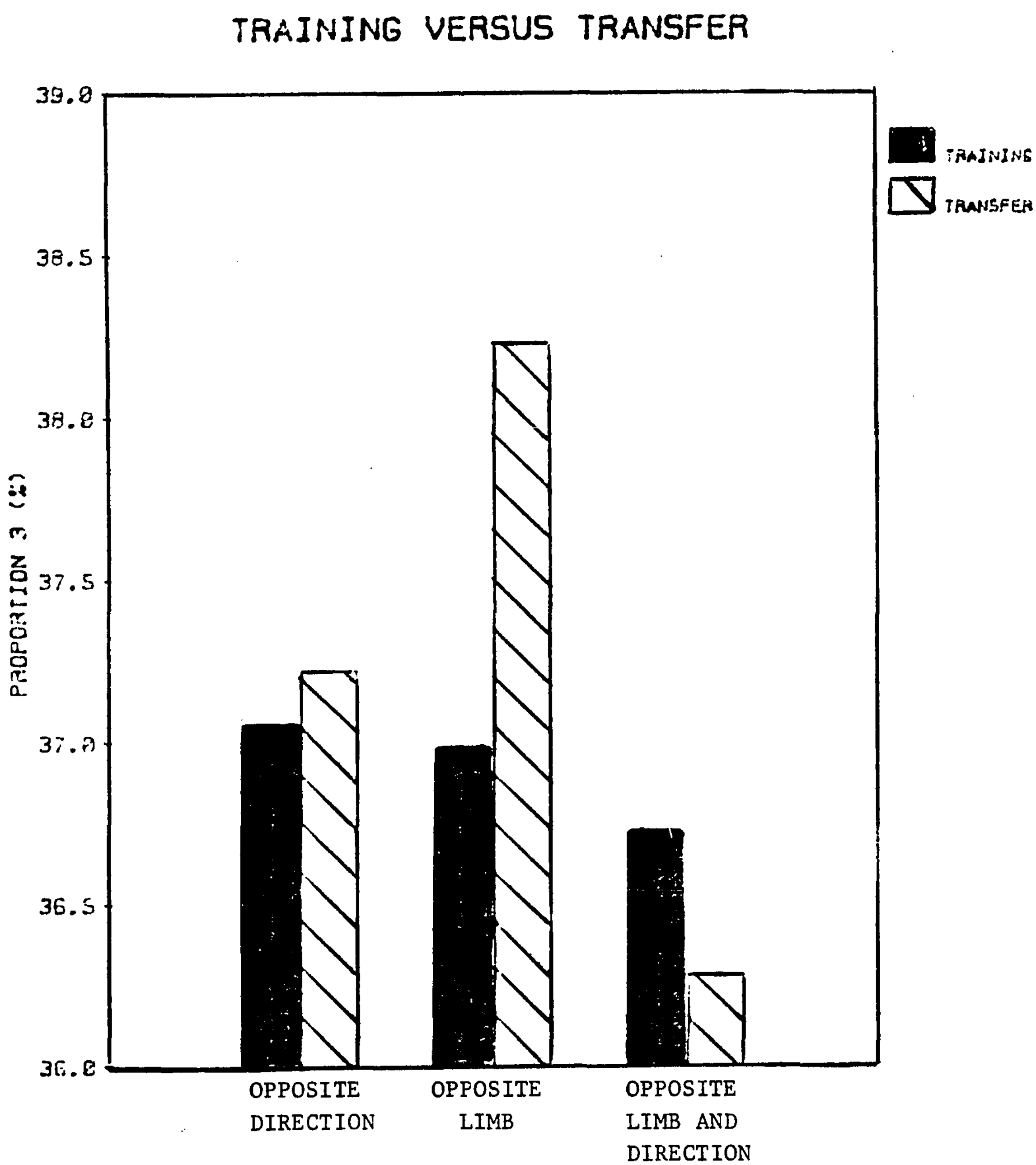
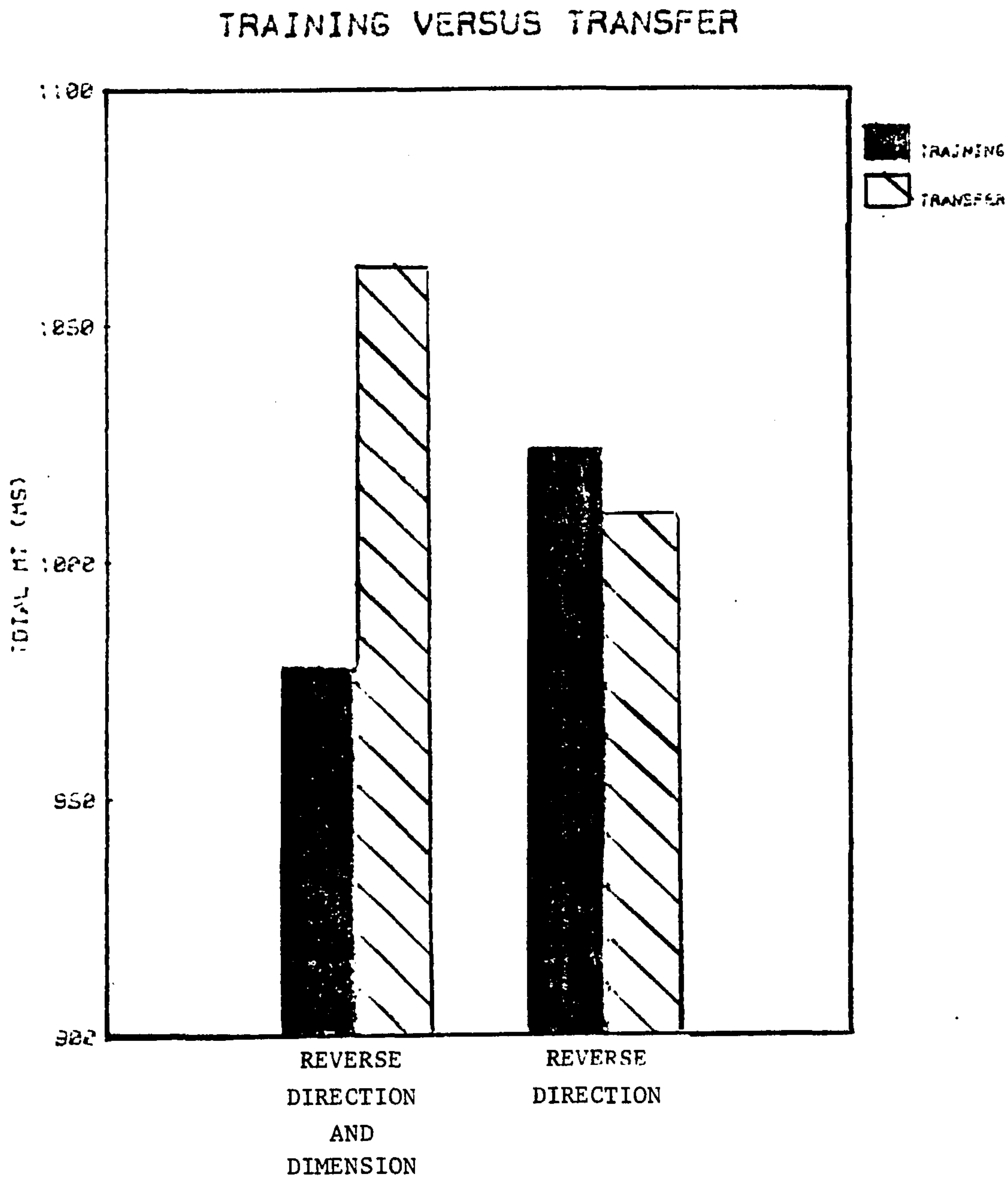
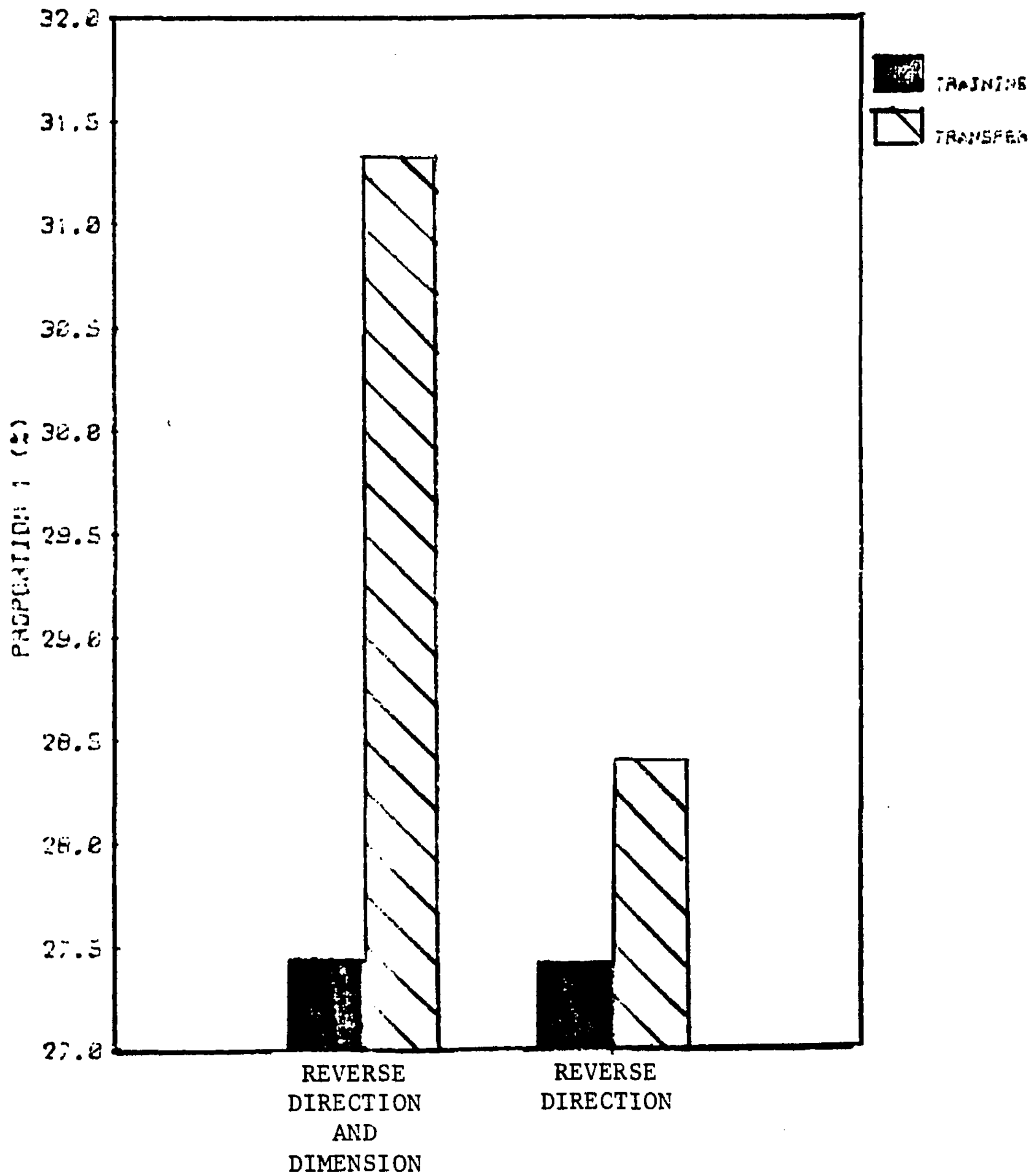
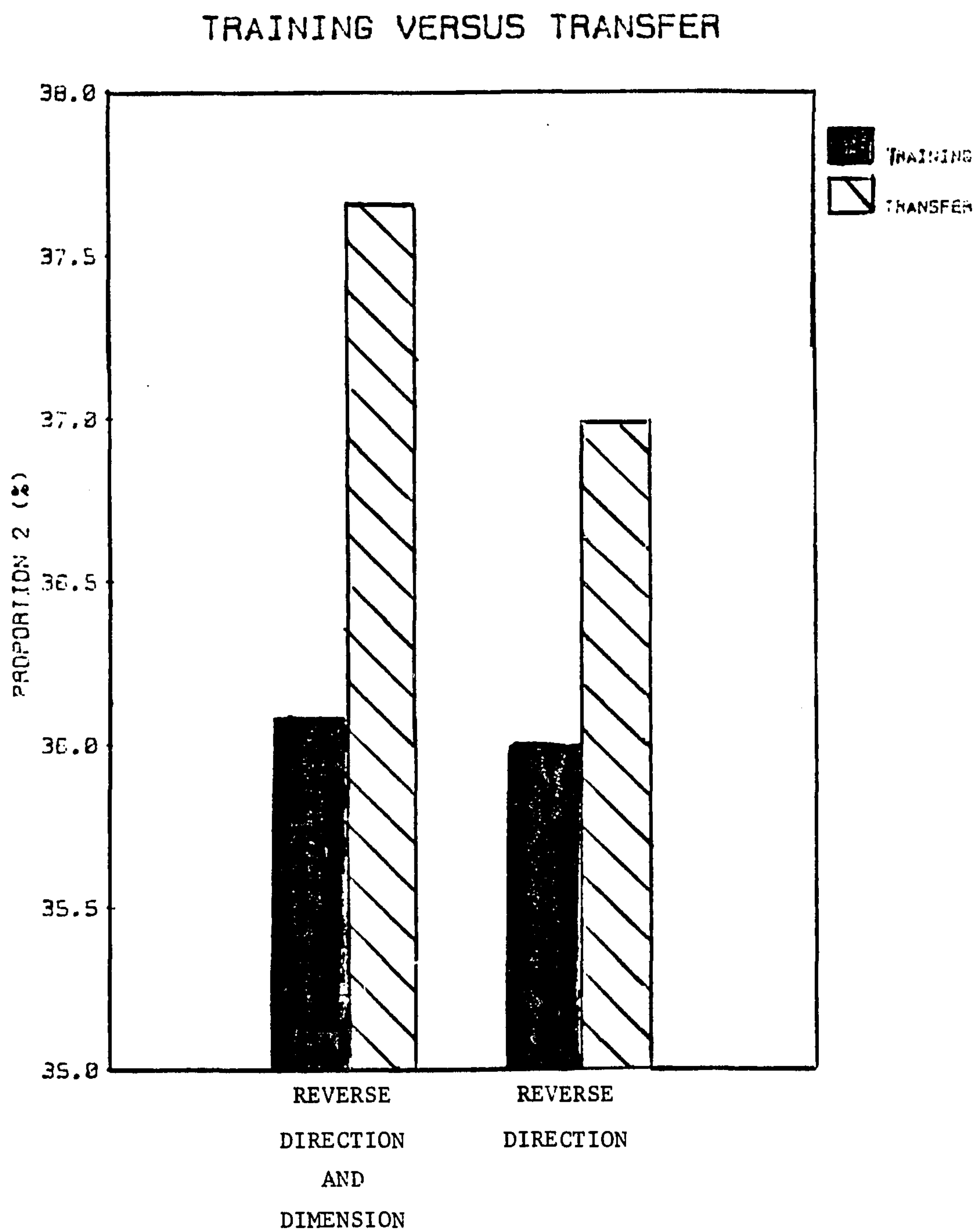
36.0
35.5
35.0
34.5
34.0
33.5
PROPORTION 2 (%)
TRAINING
TRANSFER
OPPOSITE DIRECTION
OPPOSITE LIMB
OPPOSITE LIMB AND DIRECTION


TRAINING VERSUS TRANSFER
39.0
38.5
38.0
37.5
37.0
36.5
36.0
PROPORTION 3 (%)
TRAINING
TRANSFER
OPPOSITE DIRECTION
OPPOSITE LIMB
OPPOSITE LIMB AND DIRECTION

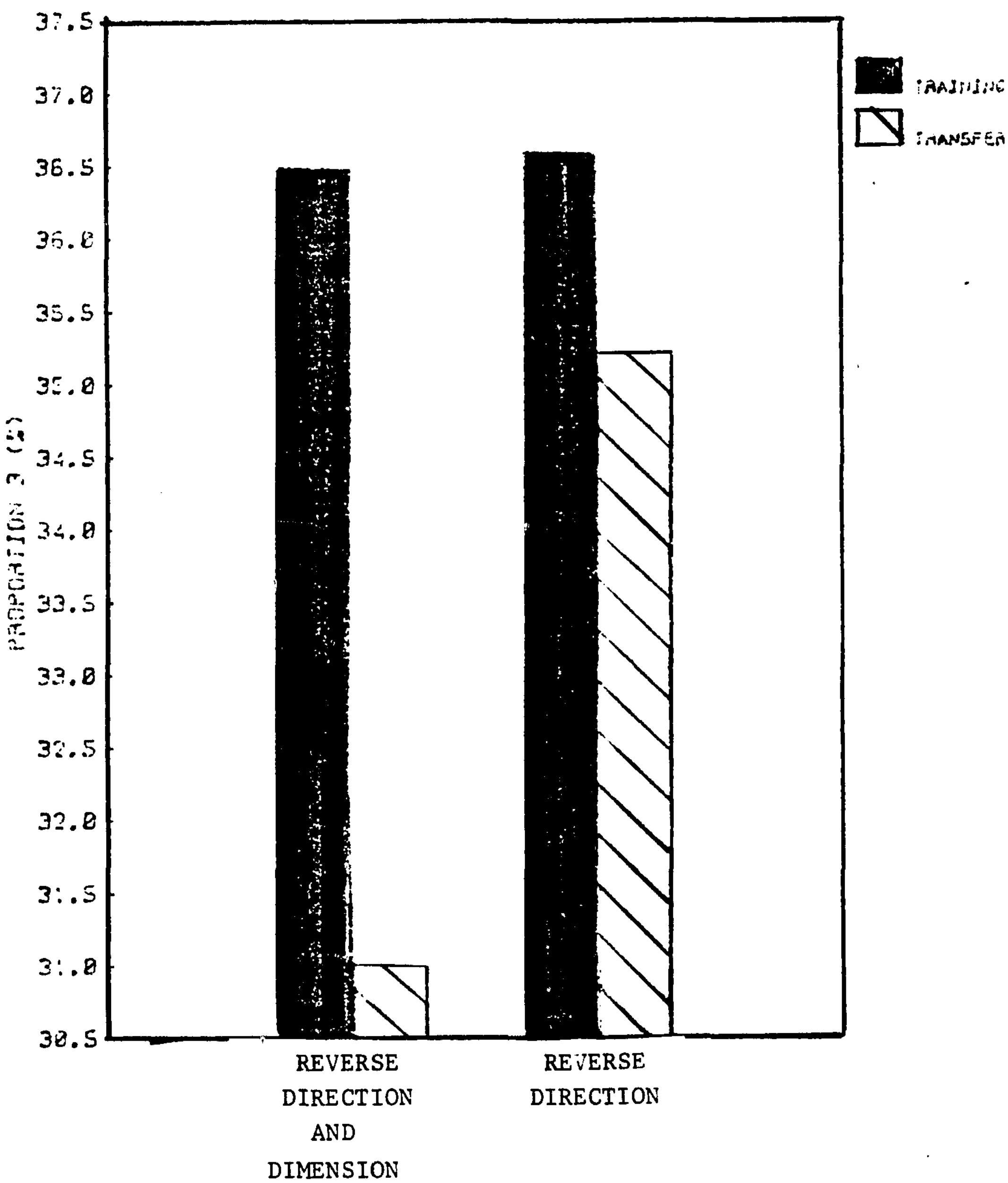

TRAINING VERSUS TRANSFER
TRAINING
TRANSFER
REVERSE DIRECTION AND DIMENSION
REVERSE DIRECTION

TRAINING VERSUS TRANSFER




TRAINING VERSUS TRANSFER
38.0
37.5
37.0
36.5
36.0
35.5
35.0
PROPORTION 2 (%)
TRAINING
TRANSFER
REVERSE DIRECTION AND DIMENSION
REVERSE DIRECTION

TRAINING VERSUS TRANSFER



APPENDICES

APPENDIX A

A Contrast of the Traditional Views of Motor Control Theory Versus An Action Systems Approach

A Contrast of the Traditional Views of Motor Control Theory Versus An Action Systems Approach

How individuals produce coordinated or patterned movements has been an issue of major concern to those researching the areas of human performance and motor skills. Historically two diverging areas of control processes have emerged. Primarily these modes of control have been based upon an efferent/afferent output distinction that is evident within the central nervous system. In contrast, a third area of motor control has emerged that departs from the previous modes of control on several issues. It is the aim of this paper to establish the framework in which the action systems approach is characterized and to note the differences and similarities between it and the traditional motor control theories.

The peripheralist theory of control was established in the late 1800's and partially form the work of Mott and Sherrington (1895) who found that muscle sensation was important to control of the limbs in monkeys. When completely deafferented, they found that the limb was virtually paralyzed and grasp was abolished. This finding led researchers to believe that afferent information from the muscles was necessary for high levels of movement execution. The importance of feedback information from the periphery led Adams (1971) to propose a closed loop system of control for motor skills.

Adams proposed a series of traces in which movements were inititated and corrected through an interaction of peripheral feedback and knowledge of results. Within this theory, movement initiation and movement selection are under the control of a memory trace. Once the movement is underway, a reference mechanism is developed to determine the correctness of the movement response. This mechanism, labelled the perceptual trace is acquired across a series of practice trials. On any given trial, the individual compares the feedback generated by the response to the perceptual trace. When the perceptual trace and the feedback match, the movement is being performed correctly. If a mismatch occurs, the individual attempts to correct the response and eliminate the error. For every movement response a perceptual trace is laid down so that a distribution of traces resulting from the responses on the all the learning trials is established. In order for motor skill learning to occur, knowledge of results (KR) about the adequacy of the last movement is used in relation to the perceptual trace in order to make the next movement better than the last one.

Most of the evidence to support Adams' (1971) closed loop theory of motor skills has evolved from studies in which movements are learned under various manipulations of KR. These studies have manipulated KR precision (Trowbridge & Cason, 1932), the KR delay interval (Bilodeau & Bilodeau, 1958; Boulter, 1963; Lorge & Thorndike, 1935), the post KR interval (Bourne & Bunderson, 1963; Croll, 1970), and KR withdrawal effects (Bilodeau, Bilodeau, & Schumsky, 1959; Boulter, 1963, 1964). Although this theory seems to be able to account for movements that are self paced or slow positioning movements to experimenter defined targets, the inability of this theory to account for the coordination and execution of rapid movements (Newell, 1974; Schmidt & White, 1972; Schmidt & Wrisberg, 1973), movements in which animals or individuals had been deafferented (Kelso, 1977; Kelso, Holt, & Flatt, 1980; Lashley, 1917; Taub & Berman, 1968), and movements of varying complexity (Henry &

Rogers, 1960) provided investigators the impetus to present a centralist based theory of control.

The centralist based theory of control in motor skills evolved from the idea that the central nervous system structured a series of commands which in turn determined the pattern of movement without response to peripheral feedback (Keele, 1968; Lashley, 1951). This concept, called a motor program, was originally based upon the idea that coordinated movements could be performed without peripheral feedback.

This theory was modified to allow feedback based corrections following one reaction time and to emphasize that motor programs were actually abstract representations of movement patterns (Pew, 1974; Schmidt, 1975). This abstract representation of movement has been labelled a generalized motor program and is roughly analagous to a computer program (Gentner, 1985; Reed, 1982). The generalized motor program is thought to be formed in the central nervous system and contains the detailed information required to carry out a movement. The program requires response specifications, that determine how the program is to be carried out. Given the response specifications the program can be run off, with all the details of the movements determined in advance (Schmidt, 1976). For very rapid responses, movements completed in less than one RT, a movement error can occur. However, in movements longer than a RT, movement corrections or modifications can be performed and are based upon feedback information from the periphery.

Schmidt (1982) has further postulated that the abstract representation of a learned movement pattern is coded in a form that defines the relative timing and relative amplitude of the pulses of muscular force that are produced. According to Schmidt (1984) the central structure determines not only the pulses to the relevant musculature but also the durations and the relative sizes of the amplitude of an impulse burst patterns. This central structure is generalized in terms of certain patterns (e.g., overarm throwing) and, depending upon the demands of a particular action, the program supplies all of the values necessary for the required response. These values are called parameters and are easily modified without changing the underlying structure of the central commands.

Recent evidence to indicate that movement is not solely under central control (Gentner, 1982; Gentner, 1985; Turvey, Shaw, & Mace, 1978) has provided researchers with the idea that a mixed approach which employed a combination of peripheral and central commands might be a better framework in which to study skilled patterns of movement. An action systems theory employing this mixed model has been primarily adapted from Bernstein's (1967) idea of functional systems and Gibson's (1977) theory of affordances. This approach would argue that actions are realizations of what the environment affords the animal's perceptual systems and that these perceptual or functional systems are controlled in terms of environmental affordances. Partly this idea of functional action systems has been derived from Bernstein's work based on the "physiology of activity". This notion would suggest that an animal is in a constant state of dis-equilibrium with it's environment, requiring not that it react to stimuli, but rather that it act continually to reevaluate it's actions in respect to the ever changing environmental constraints. This point, which is emphasized by an action system approach, is a major departure from the traditional views that are based on the idea that skilled performances can be decomposed into patterns of bodily displacement. The traditional central and peripheral views of control define and attempt to study the components of skill in biomechanical, anatomical or physical constructs. Contrary to this idea of neurobehavioral units and their displacements, an action systems approach does not deny the existence of neurobehavioral units, rather it is based upon the assumption that actions are defined in terms of ecological units and that skill taxonomy is based upon individual goals. An action system approach is also based upon the notion that evolution has resulted in a number of autonomous action systems (see Reed, 1982 for a review) which work in their own specific way to adhere to specific functions. Within an action systems approach any given movement (as determined by the traditional approaches) may play a larger role within any number of action systems. There are no peripheral and central distinctions within an action system. That is, afferent and efferent centers of activity are integrated throughout the movement control systems.

More specifically central commands do not have univocal effects, they are context conditioned. Central commands are dependent on ongoing motor and/or sensory activity. Evidence to support this idea has come from perturbation studies in which afference functions not only as a feedback mechanism but also serves to influence the physical dynamics of the central command system (Bizzi, 1980; Kelso, Holt, & Flatt, 1980). For example, Bizzi has shown that deafferented monkeys cannot accomodate to perturberations, but can achieve a previously learned movement (prior to deafferentation) when perturberation is eliminated. This finding has led other investigators to conclude that the central nervous system acts as a complex interactive structure of input/output loops versus the traditional central versus peripheral debates (Grillner, 1975; Stein, 1978).

Another distinction between action systems and traditional views that was briefly mentioned above is the idea that actions are not comprised of physical displacements within a spatial orientation framework. Traditional approaches have held that the motor problem facing a brain or a computer is one of producing outputs that will yield a certain displacement in space-time (Arbib, 1981; Greene, 1982). In contrast, an actions systems approach would argue that people move within their environment rather than some spatio/temporal aspect. Instead of having a motor control system which produces displacements and a cognitive system which constrains the motor system to act adaptively, Reed (1985) has suggested that an action system coordinates a series of subsidiary actions rather than displacing a limb or a body. Actions then, differ from movements in the respect that actions are composed of two functionally specific components. The first of these components involves the actor orienting his or her body and limbs and perceptual systems to the environment. The second component requires that the actor adapt the orientation of the body and the perceptions so as to effect the desired changes within the environment.

Evidence to support the notion of functional systems within an action systems framework has basically come from studies of simple reflex movement like stepping (Forssberg, Grillner, & Rossignol, 1977) and chewing (Lund & Rossignol, 1981) which support the notion that reflexes are attuned to the current phase of the movement. Therefore, the determinants of any action are a complex relation of the forces within the environment and the initial biological and physical conditions on the animal. Animals use the perceptual information they gain from the environment to regulate their postures and movements without regard to specific central "commands" to regulate specific effects (Reed, 1984). For example, Lee, Lishman, and Thomson (1982) found that the stride rate was modified just prior to take-off during running long jump approaches. In this situation the runner used optical information to specify the time it would take to strike the take-off board and in conjunction with this information regulated the pace of the run. According to Reed, optical information could not issue any central commands to the neuromuscular system, thus the availability of this perceptual information allowed the individual to regulate the relevant parameters (i.e., force output, rhythm, and timing) according to the specific demands of the situation.

Another distinction between traditional views of control and an action systems approach is based upon evidence that has been gathered from postural adjustment studies. Generally these studies have supported neither a purely central command system nor a purely feedback based system of control. Primarily postural perturberation studies have indicated that individuals in non-support show adjustments in posture after short latencies when perturberations are administered randomly (Cordo & Nasher, 1982). Evidence has also indicated that subjects who receive unexpected arm loadings use peripheral information from the muscalature to drive adjustments to posture (Nasher & Forssberg, 1986). Reed (1985) has argued that these postures reflect functional specificity rather than simply adaptation of the body to movement displacements. These adjustments are functional because they all share the common goal of adjusting posture around the individual's center of gravity.

In terms of traditional approaches to control of movement, a major difference between the central and peripheral views and an action systems approach is that movement reproduction in terms of the traditional views has been based solely upon individual movement displacements without regard to any adaptations the body must make to successfully perform the movement goal. However, in terms of an action system the control of any action is based upon postures and movements nested within postures. Movements in an action systems framework have been defined as the change from one posture to another with the major goal of the posture being to enable the visual system to be oriented to the environment at all times. Through the use of the visual system the individual gains expropriospecific information (Lee, 1978) and uses this information to guide meaningful movements and postures based upon the environmental constraints. Although in many instances these perceptions may be consciously driven, Gibson (1979) has defined perception as:

> **"A perceiver is aware of her existence in a persisting environment and is also aware of the movements relative to the environment... The term awareness is used to imply a direct pickup of the information, not necessarily consciousness"** (p. 249).

Another distinction between traditional approaches and an action systems viewpoint centers around the types of tasks chosen for experimental manipulations and study. Traditional viesw in terms of task selection have not always selected tasks that may generalize to real world settings. Although many exceptions may apply, a typical lab task is designed so that it can be manipulated and fit nicely within statistical methods of design. On the other hand the tasks that are chosen for study employing an action systems approach typically employ "real world" tasks or a task that is common to the everyday routine of human events. The goal of the action system with these tasks is to define the organization of action in terms of how the various streams of activity are nested into unified acts. By studying these unified acts rather than specific neurobehavioral units, an attempt is made to discover the range of variations in order to determine how various ecological systems are nested together to form everyday acts. By studying these variations of everyday tasks, an action theorists would attempt to ascertain the general principles that apply to the control of postures and movements (Reed, 1985).

In summary, the purpose of this review was to examine the nature of the differences between the traditional views of motor control an an action theory framework for the study of movement. Primarily two major differences between these have been established. The first is based upon how movements are classed. The traditional peripheral and central theories of motor control have been based upon the assumption that movements can be investigated in terms of neurobehavioral units and their displacements. Although an action system approach does not deny the fact that these units exist, they choose to say that actions are defined in terms of ecological units and that skill taxonomy is based upon individual goals. Therefore an action systems approach does not try to breakdown skills in terms of individual components and their displacements, they choose to think of skills as a functionally based act which has evolved over time to form a variety of autonomous action systems. The second disctinction is centered around the idea that peripheral and central commands have univocal effects. Evidence from postural studies has indicated that commands whether centrally or peripherally generated are context conditioned. That is, these commands (say in postural modifications) are evident, but cannot solely explain the adjustments in posture that are common occurrences. Therefore, the action system approach is a mixed model approach of central, peripheral, and reflexive control that is based on functionally specific units that are tied to an individual's perceptual system. It is the employment of the perceptual system and the idea of functionally specified movement that truly distinguish this approach from the existing peripheral and central approaches.

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Appendix B

Individual Instruction Sheet

Thank you for participating in this experiment. The pupose of this task is to perform a three-part movement pattern as rapidly as possible with the right hand. The eraser-end of a pencil should be used to touch the targets. The start button should be depressed as soon as a low-sounding buzzer is heard. Following this warning signal the red light will appear. When the light turns on move as rapidly as possible to the 3 target positions. After each movement trial your response times will be indicated on the monitor screen. Lower or smaller times indicate faster performance.

Please inform the experimenter if you should miss either target with your pencil. You will be monitored to insure that your movements continually increase in speed. Remember that your goal is to respond as quickly as possible on every trial. In order to receive full credit for this experiment you are required to perform within a maximum number of errors each day. If you exceed more than ten errors per day you will be dropped from the experiment and receive only partial credit.

If you have any questions please feel free to ask your experimenter.

APPENDIX C

MANOVA and ANOVA Tables

Table 2

Manova for Experiment 1 Data on Total MT, RT, Proportion 1, Proportion 2, and Proportion 3

Source	
Condition	F(5,18) = 0.64
Treatment	F(5,18) = 29.99
T*C	F(5,18) = 3.02
Block(T)	F(40,752) = 1.53
Condition(B*T)	F(40,752) = 1.07
Transfer Contrasts	
Block 1 vs 2, 3, 4, 5	F(5,172) = 3.85
Block 2, 3 vs 4, 5	F(5,172) = 2.05

Table 3

Total MT ANOVA for Experiment 1

Source	df	SS	F
Condition	1	101529.90	0.92
ID(Condition)	22	2439565.75	
Treatment	1	1550858.83	167.95
CxT	1	116120.94	12.58
ID(CxT)	22	203145.34	
Block(T)	8	106621.55	4.19
C(BxT)	8	17568.69	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	47522.31	14.93
Block 2,3 vs Block 4,5	1	28326.93	8.90

Table 4

RT ANOVA for Experiment 1

Source	df	SS	F
Condition	1	144.24	0.02
ID(Condition)	22	187278.25	
Treatment	1	90.05	0.16
CxT	1	28.19	0.05
ID(CxT)	22	12358.54	
Block(T)	8	4378.17	1.96
C(BxT)	8	2483.84	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	189.39	0.68
Block 2,3 vs Block 4,5	1	32.30	0.12

Table 5

Proportion 1 ANOVA for Experiment 1

Source	df	SS	F
Condition	1	58.12	0.25
ID(Condition)	22	5026.51	
Treatment	1	214.06	1.41
CxT	1	108.62	0.72
ID(CxT)	22	3329.25	
Block(T)	8	1233.50	0.99
C(BxT)	8	1067.90	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	4.52	0.03
Block 2,3 vs Block 4,5	1	0.54	0.00

Table 6

Proportion 2 ANOVA for Experiment 1

Source	df	SS	F
Condition	1	3.72	0.74
ID(Condition)	22	711.08	
Treatment	1	8.95	1.96
CxT	1	19.34	4.23
ID(CxT)	22	100.55	
Block(T)	8	3.22	0.58
C(BxT)	8	6.33	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.00	0.01
Block 2,3 vs Block 4,5	1	0.19	0.27

Table 7

Proportion 3 ANOVA for Experiment 1

Source	df	SS	F
Condition	1	8.82	0.36
ID(Condition)	22	534.98	
Treatment	1	26.02	7.06
CxT	1	5.27	1.43
ID(CxT)	22	81.06	
Block(T)	8	7.18	0.99
C(BxT)	8	5.91	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	4.89	5.39
Block 2,3 vs Block 4,5	1	1.51	0.22

Table 8

Manova for Experiment 2 Data on Total MT, RT, Proportion 1, Proportion 2, and Proportion 3

Source	
Condition	F(10,58) = 1.61
Treatment	F(5,58) = 15.43
T*C	F(10,58) = 3.70
Block(T)	F(40,1136) = 2.97
Condition(B*T)	F(80,1255) = 1.06
Transfer Contrasts	
Block 1 vs 2, 3, 4, 5	F(5,260) = 6.59
Block 2, 3 vs 4, 5	F(5,260) = 0.24

Table 9

Total MT 3 ANOVA for Experiment 2

Source	df	SS	F
Condition	2	109988.47	5.04
ID(Condition)	33	3599865.33	
Treatment	1	5891946.71	68.82
CxT	2	5434325.62	31.72
ID(CxT)	33	282511.87	
Block(T)	8	77125.84	8.00
C(BxT)	16	24221.19	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	32093.40	26.64
Block 2,3 vs Block 4,5	1	154.17	0.13

Table 10

RT ANOVA for Experiment 2

Source	df	SS	F
Condition	2	17355.33	0.99
ID(Condition)	33	289055.15	
Treatment	1	6266.15	9.61
CxT	2	1047.41	0.80
ID(CxT)	33	215171.92	
Block(T)	8	13399.93	7.40
C(BxT)	16	3689.37	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	1578.27	7.01
Block 2,3 vs Block 4,5	1	4.69	0.02

Table 11

Proportion 1 ANOVA for Experiment 2

Source	df	SS	F
Condition	2	8.67	0.09
ID(Condition)	33	1609.56	
Treatment	1	97.14	23.73
CxT	2	0.50	0.06
ID(CxT)	33	135.06	
Block(T)	8	13.67	2.14
C(BxT)	16	13.60	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.67	0.84
Block 2,3 vs Block 4,5	1	0.25	0.31

Table 12

Proportion 2 ANOVA for Experiment 2

Source	df	SS	F
Condition	2	28.72	0.25
ID(Condition)	33	951.18	
Treatment	1	25.60	12.62
CxT	2	37.92	8.37
ID(CxT)	33	71.68	
Block(T)	8	9.52	1.80
C(BxT)	16	14.31	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	1.17	1.76
Block 2,3 vs Block 4,5	1	0.17	0.26

Table 13

Proportion 3 ANOVA for Experiment 2

Source	df	SS	F
Condition	2	10.27	0.25
ID(Condition)	33	672.19	
Treatment	1	26.68	12.62
CxT	2	35.37	8.37
ID(CxT)	33	69.75	
Block(T)	8	6.31	1.14
C(BxT)	16	8.69	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.31	0.45
Block 2,3 vs Block 4,5	1	0.84	1.21

Table 14

Manova for Experiment 3 Data on Total MT, RT, Proportion 1, Proportion 2, and Proportion 3

Source	
Condition	F(10,58) = 1.52
Treatment	F(5,58) = 13.79
T*C	F(10,58) = 3.56
Block(T)	F(40,1136) = 3.24
Condition(B*T)	F(80,1255) = 0.98
Transfer Contrasts	
Block 1 vs 2, 3, 4, 5	F(5,260) = 10.61
Block 2, 3 vs 4, 5	F(5,260) = 3.06

Table 15

Total MT ANOVA for Experiment 3

Source	df	SS	F
Condition	2	393840.02	1.49
ID(Condition)	33	4375105.26	
Treatment	1	767567.03	62.32
CxT	2	344685.95	13.99
ID(CxT)	33	406426.93	
Block(T)	8	171627.87	10.97
C(BxT)	16	21489.87	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	84868.73	43.41
Block 2,3 vs Block 4,5	1	4064.06	2.08

Table 16

RT ANOVA for Experiment 3

Source	df	SS	F
Condition	2	1271.76	0.08
ID(Condition)	33	265212.70	
Treatment	1	3180.28	3.38
CxT	2	4294.23	2.29
ID(CxT)	33	31008.23	
Block(T)	8	4298.48	2.32
C(BxT)	16	4692.66	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	6.61	0.03
Block 2,3 vs Block 4,5	1	1899.51	8.20

Table 17

Proportion 1 ANOVA for Experiment 3

Source	df	SS	F
Condition	2	2.62	0.03
ID(Condition)	33	1688.38	
Treatment	1	16.90	2.59
CxT	2	1.05	0.08
ID(CxT)	33	215.05	
Block(T)	8	13.49	1.76
C(BxT)	16	19.78	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.80	0.84
Block 2,3 vs Block 4,5	1	1.36	1.42

Table 18

Proportion 2 ANOVA for Experiment 3

Source	df	SS	F
Condition	2	49.51	1.52
ID(Condition)	33	537.46	
Treatment	1	55.23	8.15
CxT	2	25.35	1.87
ID(CxT)	33	223.53	
Block(T)	8	14.63	2.23
C(BxT)	16	14.03	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	1.25	1.52
Block 2,3 vs Block 4,5	1	0.44	0.54

Table 19

Proportion 3 ANOVA for Experiment 3

Source	df	SS	F
Condition	2	74.21	1.91
ID(Condition)	33	640.56	
Treatment	1	9.67	1.54
CxT	2	43.67	3.48
ID(CxT)	33	206.96	
Block(T)	8	4.97	0.93
C(BxT)	16	13.90	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.35	0.52
Block 2,3 vs Block 4,5	1	0.00	0.00

Table 20

Manova for Experiment 4 Data on Total MT, RT, Proportion 1,

Proportion 2, and Proportion 3

Source	
Condition	F(5,18) = 6.99
Treatment	F(5,18) = 21.19
T*C	F(5,18) = 14.30
Block(T)	F(40,752) = 3.19
Condition(B*T)	F(40,752) = 0.77
Transfer Contrasts	
Block 1 vs 2, 3, 4, 5	F(5,172) = 9.49
Block 2, 3 vs 4, 5	F(5,172) = 5.21

Table 21

Total MT ANOVA for Experiment 4

Source	df	SS	F
Condition	1	806.37	0.00
ID(Condition)	22	5018919.89	
Treatment	1	76715.18	8.66
CxT	1	148639.12	16.78
ID(CxT)	22	194850.63	
Block(T)	8	159451.80	8.90
C(BxT)	8	16487.19	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	72912.75	32.56
Block 2,3 vs Block 4,5	1	35494.00	5.85

Table 22

RT ANOVA for Experiment 4

Source	df	SS	F
Condition	1	23.27	0.00
ID(Condition)	22	217780.46	
Treatment	1	1361.17	0.43
CxT	1	12009.59	3.80
ID(CxT)	22	69496.54	
Block(T)	8	5852.89	3.81
C(BxT)	8	2005.33	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	1272.33	6.62
Block 2,3 vs Block 4,5	1	387.85	2.02

Table 23

Proportion 1 ANOVA for Experiment 4

Source	df	SS	F
Condition	1	130.56	2.19
ID(Condition)	22	1311.16	
Treatment	1	355.63	19.24
CxT	1	127.47	6.90
ID(CxT)	22	406.71	
Block(T)	8	9.21	1.01
C(BxT)	8	5.12	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	0.50	0.44
Block 2,3 vs Block 4,5	1	0.00	0.00

Table 24

Proportion 2 ANOVA for Experiment 4

Source	df	SS	F
Condition	1	28.09	1.56
ID(Condition)	22	395.08	
Treatment	1	58.49	4.31
CxT	1	21.03	1.55
ID(CxT)	22	298.55	
Block(T)	8	6.01	0.90
C(BxT)	8	0.63	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	1.87	2.24
Block 2,3 vs Block 4,5	1	0.63	0.75

Table 25

Proportion 3 ANOVA for Experiment 4

Source	df	SS	F
Condition	1	279.76	13.86
ID(Condition)	22	444.20	
Treatment	1	702.49	63.19
CxT	1	252.05	22.67
ID(CxT)	22	244.61	
Block(T)	8	10.34	1.51
C(BxT)	8	2.17	
Transfer Contrast			
Block 1 vs Block 2,3,4,5	1	4.32	5.06
Block 2,3 vs Block 4,5	1	0.52	0.62

APPENDIX D

BLOCK MEANS AND STANDARD DEVIATIONS

Table 26

Block Means and Standard Deviations for Experiment 1

Similar Dimensional New Spatial Pattern Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	1026	286	26.27	36.15	37.58
sd	1	119	30	3.34	2.69	1.21
M	2	1017	280	26.66	35.77	37.57
sd	2	110	27	3.31	2.96	1.32
M	3	990	275	26.97	35.51	37.51
sd	3	117	24	3.00	2.61	1.71
M	4	976	269	27.27	35.42	37.29
sd	4	134	28	3.23	2.32	2.03
M	5	976	265	26.95	35.76	37.29
sd	5	131	31	2.63	1.99	1.49
M	6	1150	279	25.88	35.00	39.11
sd	6	111	28	2.20	1.82	1.40
M	7	1120	269	26.69	34.71	38.59
sd	7	124	32	2.63	1.37	1.65
M	8	1105	267	27.14	34.71	38.15
sd	8	89	29	2.61	1.66	1.52
M	9	1101	273	26.94	34.79	38.27
sd	9	122	31	2.75	1.56	1.44
M	10	1108	281	26.83	34.96	38.21
sd	10	122	26	2.72	1.40	1.63

Increased Dimension Same Spatial Pattern Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	1042	282	27.88	34.79	38.27
sd	1	111	36	3.32	1.87	2.36
M	2	1043	279	27.59	35.03	37.37
sd	2	113	44	2.40	2.90	1.98
M	3	1030	272	27.59	34.74	37.66
sd	3	134	34	2.16	1.89	2.16
M	4	1013	268	26.66	34.77	37.56
sd	4	128	33	2.94	2.55	2.71
M	5	1026	278	27.32	35.00	37.67
sd	5	122	38	2.00	1.96	2.36
M	6	1271	275	27.21	34.72	38.06
sd	6	119	33	2.26	1.81	1.98
M	7	1252	279	27.33	34.68	37.98
sd	7	120	38	2.96	1.86	1.97
M	8	1235	277	26.85	35.16	37.99
sd	8	107	40	2.84	1.62	1.93
M	9	1188	270	27.25	35.05	37.70
sd	9	94	38	3.08	2.43	1.82
M	10	1185	274	27.54	34.84	37.61
sd	10	103	30	2.82	2.11	1.81

Table 27

Block Means and Standard Deviations for Experiment 2

Same Index of Difficulty Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	936	279	27.12	35.83	36.83
sd	1	114	40	2.88	2.17	1.80
M	2	902	262	27.00	36.58	36.75
sd	2	124	34	3.04	2.42	1.82
M	3	915	263	26.58	36.58	36.75
sd	3	120	28	3.20	2.60	1.83
M	4	910	259	27.25	36.08	36.67
sd	4	118	35	3.10	3.03	1.56
M	5	912	260	27.08	36.50	36.58
sd	5	119	34	3.14	2.46	1.66
M	6	954	268	28.08	34.75	37.16
sd	6	122	29	3.17	2.56	1.40
M	7	936	259	28.00	34.91	37.08
sd	7	115	29	2.76	2.06	1.67
M	8	938	263	27.91	34.91	36.91
sd	8	106	28	3.05	1.97	1.56
M	9	933	259	28.00	34.91	37.08
sd	9	114	35	2.92	2.39	1.56
M	10	926	257	27.83	35.25	36.91
sd	10	107	30	2.55	1.95	1.31

Decreased Index of Difficulty (Amplitude) Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	970	260	26.08	36.41	37.58
sd	1	118	27	1.56	1.44	1.16
M	2	921	248	26.66	36.25	37.33
sd	2	119	29	1.77	1.86	1.37
M	3	912	252	26.50	36.33	37.16
sd	3	105	33	1.62	1.61	1.40
M	4	936	247	26.75	35.91	37.25
sd	4	124	30	1.48	1.67	1.21
M	5	900	249	27.26	36.16	36.75
sd	5	102	33	1.62	1.61	1.21
M	6	785	243	27.50	36.58	36.75
sd	6	117	29	2.61	2.23	1.62
M	7	753	241	27.67	36.75	36.08
sd	7	88	34	2.61	2.23	1.62
M	8	758	239	27.67	35.83	36.50
sd	8	104	25	2.10	1.85	1.78
M	9	759	243	27.75	36.50	35.75
sd	9	121	27	1.60	1.83	1.64
M	10	763	241	27.83	36.50	37.25
sd	10	124	18	1.69	1.88	2.05

Decreased Index of Difficulty (Target Size) Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	872	282	26.41	36.41	37.25
sd	1	113	39	2.35	1.24	1.42
M	2	843	260	26.58	36.50	36.83
sd	2	102	39	2.06	1.00	1.74
M	3	826	253	27.00	36.33	36.50
sd	3	108	46	2.26	1.07	1.67
M	4	829	247	27.25	36.08	36.75
sd	4	109	40	2.37	0.99	1.81
M	5	842	249	27.41	35.75	36.83
sd	5	123	37	2.46	1.60	1.94
M	6	783	256	28.50	35.33	36.16
sd	6	102	43	.541	2.01	1.74
M	7	744	256	28.50	35.33	36.16
sd	7	102	42	2.54	2.01	1.74
M	8	721	244	28.16	35.91	36.00
sd	8	106	29	2.58	1.42	2.27
M	9	728	241	28.16	35.91	36.17
sd	9	93	28	2.28	1.44	1.53
M	10	729	249	27.91	35.66	36.17
sd	10	91	36	2.39	1.23	1.99

Table 28
Block Means and Standard Deviations for Experiment 3

Opposite Direcion Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	1000	269	27.58	35.67	36.91
sd	1	90	32	1.73	1.61	1.44
M	2	950	254	27.91	35.33	36.83
sd	2	126	30	1.50	1.87	1.52
M	3	949	255	26.91	35.58	37.16
sd	3	137	31	1.44	1.56	1.24
M	4	946	257	27.50	35.58	37.17
sd	4	129	33	1.73	1.72	1.11
M	5	937	255	27.58	35.58	36.91
sd	5	110	25	2.06	1.37	1.67
M	6	1005	278	28.33	34.91	36.83
sd	6	97	38	2.42	1.31	1.85
M	7	966	271	27.91	34.41	37.50
sd	7	104	34	2.50	1.24	1.88
M	8	967	266	28.00	35.16	37.00
sd	8	106	29	2.82	1.80	1.76
M	9	955	276	28.17	34.33	37.41
sd	9	99	31	2.63	1.21	1.92
M	10	942	274	28.17	34.33	37.42
sd	10	116	42	2.37	1.30	1.50

Opposite Limb Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	994	264	27.00	35.58	37.42
sd	1	148	22	2.73	1.88	1.31
M	2	952	265	27.25	35.91	36.91
sd	2	140	18	2.14	1.16	1.56
M	3	924	256	27.25	36.00	36.75
sd	3	120	25	2.22	1.85	1.81
M	4	927	260	27.25	35.67	37.08
sd	4	139	26	2.70	1.72	1.83
M	5	970	274	28.33	34.91	36.75
sd	5	169	41	1.87	1.31	1.60
M	6	1157	256	27.33	34.58	38.33
sd	6	121	19	2.80	1.97	1.96
M	7	1121	260	27.50	34.25	38.25
sd	7	132	16	2.47	1.99	1.50
M	8	1092	260	27.50	34.25	38.25
sd	8	124	21	2.46	2.17	1.28
M	9	1097	269	28.00	34.17	38.00
sd	9	135	22	2.44	2.08	1.20
M	10	1105	269	28.17	33.75	38.17
sd	10	135	34	2.28	1.81	1.52

Opposite Limb and Direction Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	949	268	27.75	35.33	37.00
sd	1	84	32	3.27	2.10	2.00
M	2	902	260	27.25	36.16	36.58
sd	2	117	29	3.38	1.75	1.88
M	3	899	271	27.26	35.83	36.83
sd	3	123	35	3.16	1.87	2.23
M	4	902	257	27.25	35.83	36.83
sd	4	115	30	3.57	1.64	2.40
M	5	913	268	27.58	35.67	36.83
sd	5	104	37	3.17	1.83	2.67
M	6	1069	269	27.58	35.67	36.17
sd	6	145	43	2.50	1.77	1.47
M	7	1017	269	27.91	35.67	36.17
sd	7	155	36	2.42	1.49	1.40
M	8	1004	262	28.08	35.75	36.00
sd	8	136	46	2.67	1.81	2.04
M	9	993	275	27.91	35.83	36.33
sd	9	134	41	3.26	1.85	1.96
M	10	1011	274	28.08	35.67	36.08
sd	10	150	49	2.15	1.82	2.11

Table 29

Block Means and Standard Deviations for Experiment 4
Reverse Direction Reverse Metric Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	1007	250	26.88	36.26	36.84
sd	1	162	59	4.05	2.43	1.88
M	2	964	249	27.57	36.00	36.42
sd	2	141	53	3.56	2.31	1.68
M	3	982	248	27.38	35.84	36.77
sd	3	126	54	4.55	2.74	2.19
M	4	962	246	27.85	35.84	36.30
sd	4	117	52	4.32	2.18	2.49
M	5	973	248	27.48	36.47	36.04
sd	5	148	49	4.37	2.62	2.13
M	6	1101	272	30.95	37.51	31.52
sd	6	137	33	2.76	1.16	2.27
M	7	1089	268	31.42	37.70	30.86
sd	7	136	31	2.10	1.28	1.92
M	8	1075	262	31.36	37.81	30.81
sd	8	116	32	2.51	1.62	2.39
M	9	1028	269	31.56	37.45	30.84
sd	9	148	35	2.43	2.03	2.31
M	10	1021	265	31.34	37.81	30.84
sd	10	148	35	2.34	1.62	2.42

Reverse Direction Transfer Condition

	Block	Total MT	RT	Proportions 1	2	3
M	1	1070	277	27.13	36.25	36.61
sd	1	174	37	2.35	2.20	1.52
M	2	1012	262	27.15	36.19	36.65
sd	2	192	33	2.40	2.32	2.24
M	3	1015	257	27.27	35.96	36.76
sd	3	191	37	2.51	2.32	1.61
M	4	997	250	27.62	35.79	36.59
sd	4	183	33	2.70	2.21	1.46
M	5	1022	264	27.91	35.75	36.33
sd	5	158	36	3.23	1.04	1.87
M	6	1070	260	28.51	36.03	35.45
sd	6	177	24	2.11	1.39	1.26
M	7	1009	250	28.39	36.45	35.15
sd	7	162	21	2.33	1.34	1.56
M	8	999	245	28.37	36.69	34.94
sd	8	181	26	1.97	1.17	1.67
M	9	991	258	28.28	36.47	35.24
sd	9	188	27	2.14	1.51	1.78
M	10	979	249	28.42	36.28	35.29
sd	10	178	17	1.76	1.21	1.72

APPENDIX E

Mean Performance for Training and Transfer for Movement Segments 1, 2, 3

Table 30

Dissimilar Geometrical Transfer

Mean Performance for Training and Transfer For Movements Segment 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	951	22.5	37.3	40.3	1089	24.3	36.5	39.2	138	1.8	-0.8	-1.1	= 0
2	1112	27.4	35.5	37.1	1223	27.8	34.9	37.4	111	0.4	-0.6	0.3	≠ 0
3	832	24.7	36.6	38.7	946	26.2	34.8	39.0	114	1.5	-1.8	0.3	≠ 0
4	932	25.9	37.1	37.1	1091	23.7	37.0	39.1	159	-2.2	-0.1	2.0	≠ 0
5	1028	32.7	31.7	35.6	1159	29.0	32.5	38.9	131	-3.7	0.8	3.3	≠ 0
6	886	27.2	36.4	36.4	1005	29.6	33.7	36.8	119	2.4	-2.7	0.4	≠ 0
7	1031	23.7	37.7	36.0	1079	23.0	36.0	41.0	48	-0.7	0.8	5.0	≠ 0
8	1052	28.1	35.2	36.7	1051	26.2	35.2	38.6	-1	-2.1	0.0	0.9	= 0
9	1239	26.9	34.7	38.7	1317	28.0	33.3	38.3	78	1.1	-0.6	-0.3	= 0
10	1161	30.4	31.7	37.8	1299	27.7	33.9	38.3	138	-2.7	2.2	0.5	≠ 0
11	1073	28.7	33.7	37.7	1249	30.7	33.0	36.3	176	2.0	-0.7	-1.4	≠ 0
12	832	25.4	39.0	35.6	1099	25.4	35.7	38.9	267	0.1	-3.3	3.3	≠ 0
M	1010	27.0	35.6	36.7	1134	26.8	34.7	38.5	124	-0.2	-0.9	1.8	9 ≠ 0

Note. Training trials include the last 40 trial of Day 2 performance.

Table 31

Similar Geometrical Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	939	27.2	33.9	38.8	1255	26.2	34.7	39.1	316	-1.0	0.8	0.3	≠ 0
2	946	27.7	31.7	40.6	1142	26.4	33.0	40.6	166	-0.7	1.3	0.0	≠ 0
3	1073	26.1	38.9	35.0	1354	24.7	38.3	36.9	341	-2.4	-0.6	1.9	≠ 0
4	1183	24.6	36.2	39.2	1350	25.2	35.8	39.0	167	0.6	-0.4	0.2	≠ 0
5	895	27.0	36.6	36.4	1049	27.1	35.8	37.2	154	0.1	-0.8	0.8	≠ 0
6	1036	26.0	35.0	39.0	1268	25.2	37.0	37.8	232	-0.8	2.0	-1.2	≠ 0
7	1024	27.0	35.9	38.0	1235	26.1	36.4	36.4	211	-0.9	0.5	-1.6	≠ 0
8	1038	33.0	32.3	34.7	1191	34.7	30.9	34.4	153	1.7	-1.4	-0.3	≠ 0
9	781	30.0	34.3	35.7	1032	27.2	35.2	37.6	251	-2.8	0.9	1.9	≠ 0
10	1077	29.8	35.8	34.4	1249	30.8	34.5	34.7	172	1.0	-1.3	0.3	≠ 0
11	1074	26.6	33.0	40.4	1270	25.9	34.5	39.6	196	-0.7	1.5	-0.8	= 0
12	1033	26.1	35.5	38.4	1234	26.5	34.8	38.7	201	0.4	-0.7	0.3	≠ 0
M	1088	27.6	34.9	37.6	1219	27.2	35.1	37.7	131	-0.4	0.2	0.2	11 ≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 32

Same Index of Difficulty Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	926	22.7	39.8	37.5	942	25.0	37.1	37.9	16	2.3	-2.7	0.4	= 0
2	841	27.2	37.6	35.2	882	29.2	34.8	36.0	41	2.0	-1.8	-0.8	≠ 0
3	703	29.8	34.9	35.3	710	31.8	32.9	35.2	7	2.0	-2.0	-0.1	≠ 0
4	767	29.0	34.6	36.3	844	30.8	33.2	36.0	77	1.8	-1.4	-0.3	= 0
5	868	24.8	36.2	39.1	961	26.4	34.9	38.8	93	1.6	-1.3	-0.3	≠ 0
6	1042	25.2	34.9	40.0	1075	27.0	33.5	39.5	33	1.8	-1.4	-0.5	≠ 0
7	857	25.1	38.5	36.4	968	24.8	38.3	36.9	111	-0.3	-0.2	0.5	≠ 0
8	1042	30.5	35.1	34.4	1105	30.0	34.3	35.7	63	-0.5	-0.8	1.3	≠ 0
9	984	32.3	30.9	36.8	927	32.2	31.6	36.2	57	-0.1	0.7	-0.6	≠ 0
10	1034	22.7	39.6	37.7	1040	23.9	37.4	38.7	6	1.2	-2.2	1.0	≠ 0
11	1034	26.1	38.5	35.4	963	26.3	36.9	36.8	-71	0.2	-1.6	1.4	≠ 0
12	823	25.5	38.3	36.2	836	28.8	34.9	37.0	13	3.3	-3.9	0.6	= 0
M	910	26.7	36.6	36.7	938	28.0	34.9	37.0	28	1.3	-1.7	-0.3	9≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 33

Decreased Index of Difficulty Increased Target Size

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	598	28.5	36.7	34.8	521	31.6	35.0	33.4	77	3.1	-1.7	-1.4	= 0
2	807	28.0	35.8	36.2	727	30.5	35.8	33.7	-160	1.5	0.0	-2.5	≠ 0
3	711	26.1	36.4	37.4	688	25.9	36.7	37.3	-23	-0.2	0.3	0.1	≠ 0
4	813	25.8	36.8	37.4	805	26.6	36.2	37.2	-8	0.8	-0.6	-0.2	≠ 0
5	810	28.7	35.0	36.3	741	30.2	33.5	36.3	-69	1.5	-1.5	0.0	≠ 0
6	1006	30.2	35.9	34.8	932	29.6	35.4	35.0	74	-0.6	0.4	0.2	≠ 0
7	948	25.2	36.1	38.7	756	25.4	37.0	37.6	-192	0.2	0.9	-1.1	≠ 0
8	850	24.3	35.5	40.3	728	25.8	34.1	40.1	-122	1.5	-1.5	0.0	≠ 0
9	932	24.9	38.0	37.1	800	27.4	35.6	37.2	-132	2.5	-2.4	1.0	≠ 0
10	831	29.2	35.6	35.3	724	28.8	35.5	35.7	-107	-0.4	-0.1	0.4	= 0
11	797	24.2	38.3	37.5	634	25.5	38.3	36.2	-163	1.3	0.0	-1.3	≠ 0
12	883	29.7	35.4	34.8	837	29.4	34.9	35.7	-46	-0.3	-0.5	0.9	≠ 0
M	839	27.1	36.2	36.7	741	28.1	35.7	36.3	-98	1.0	-0.5	-0.4	10≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 34

Decreased Index of Difficulty Decreased Amplitude

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	851	25.7	37.4	36.9	775	26.2	36.9	37.0	-76	-0.5	0.5	0.1	= 0
2	823	27.0	35.9	37.1	692	28.8	36.6	34.5	-131	1.8	0.7	-2.6	≠ 0
3	1040	26.3	37.4	36.3	869	26.5	37.8	35.8	-171	-0.2	-0.4	0.5	≠ 0
4	860	28.2	35.2	36.6	764	28.1	37.3	34.7	-96	0.1	2.1	-1.9	≠ 0
5	1106	27.5	34.1	38.4	983	28.8	34.0	37.2	-123	1.3	-0.1	-1.2	≠ 0
6	935	27.2	34.9	37.8	756	31.2	33.3	35.5	-179	4.0	-1.6	-2.3	≠ 0
7	859	25.6	35.5	38.9	742	27.4	36.3	36.3	-117	1.8	-0.8	-2.6	≠ 0
8	905	24.0	38.9	37.2	575	25.0	38.8	36.2	-330	1.0	0.1	-1.1	≠ 0
9	731	27.1	35.6	37.2	632	25.0	37.7	37.3	-99	-2.1	2.1	-0.1	≠ 0
10	891	25.2	37.5	37.3	733	26.4	36.4	37.2	-158	1.2	-1.1	-0.1	≠ 0
11	1011	28.5	37.2	34.2	838	29.7	38.0	32.3	-173	1.2	0.8	-1.9	≠ 0
12	997	28.8	33.8	37.3	804	28.3	33.9	37.9	-193	-0.5	-0.1	0.6	= 0
M	917	26.8	36.1	37.1	764	27.6	36.4	36.0	-153	0.8	0.3	-1.1	10≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 35

Opposite Limb Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	993	28.0	36.0	35.5	1149	28.0	33.6	36.8	156	0.0	-2.4	1.3	≠ 0
2	906	29.5	35.8	35.0	1194	31.2	33.0	35.0	288	0.7	-2.8	0.8	≠ 0
3	1183	24.8	35.8	37.3	1193	24.2	36.6	37.4	10	0.6	-0.6	0.1	= 0
4	1058	25.0	35.8	33.0	1277	27.0	35.8	38.0	219	2.0	0.6	-1.2	≠ 0
5	644	31.8	38.5	36.5	644	29.0	34.8	35.8	232	-2.8	0.6	-0.7	≠ 0
6	858	28.8	38.5	35.8	999	31.0	38.5	36.4	141	1.2	3.5	0.6	≠ 0
7	827	27.3	34.5	37.5	934	27.8	35.4	36.0	107	0.5	0.9	-1.5	≠ 0
8	890	24.3	34.8	36.8	1107	24.4	36.0	38.4	217	0.1	1.2	1.6	≠ 0
9	1002	28.0	38.0	37.8	1192	26.8	35.6	37.8	190	1.5	-2.4	4.0	≠ 0
10	1020	27.0	35.0	38.0	1216	25.2	34.2	38.3	196	-1.8	-0.8	-0.8	≠ 0
11	919	28.3	33.0	38.3	1061	29.8	33.4	36.0	142	1.5	0.4	-2.3	≠ 0
12	1028	27.8	34.5	38.8	1175	28.0	34.5	38.2	137	0.2	0.7	-0.6	≠ 0
M	944	27.6	35.5	37.1	1114	27.7	34.8	37.2	170	0.1	-0.7	0.1	11 ≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 36

Opposite Direction Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training Total MT	Training Segment % 1	Training Segment % 2	Training Segment % 3	Transfer Total MT	Transfer Segment % 1	Transfer Segment % 2	Transfer Segment % 3	Change to Transfer Total MT	Change Segment % 1	Change Segment % 2	Change Segment % 3	Slope
1	843	28.5	34.3	37.5	850	29.8	33.8	38.2	7	1.3	-0.5	0.7	≠ 0
2	909	29.8	33.3	37.3	1101	31.4	32.8	37.3	192	1.6	-1.5	-1.3	≠ 0
3	827	27.3	36.5	39.0	913	26.0	37.0	39.0	86	-1.3	-0.5	0.0	≠ 0
4	870	26.3	37.5	37.5	901	26.6	35.6	37.8	41	0.3	-1.9	0.3	≠ 0
5	1197	28.8	35.3	33.3	1126	29.8	33.8	37.2	-71	1.0	-1.5	3.9	≠ 0
6	930	25.5	35.0	35.8	921	28.4	31.0	38.2	-9	2.9	-4.0	2.4	≠ 0
7	830	28.3	35.5	37.3	1030	28.2	34.0	38.4	200	0.1	-1.5	1.1	≠ 0
8	1148	28.5	37.8	35.0	1087	28.6	37.8	40.8	61	0.1	0.5	5.8	≠ 0
9	965	28.5	34.8	37.3	1074	25.6	36.8	37.3	109	-2.9	2.0	-.7	≠ 0
10	851	24.5	35.0	37.8	880	22.8	35.2	39.6	29	-1.7	0.2	1.8	≠ 0
11	833	27.0	35.8	36.3	889	28.6	33.0	37.2	56	1.6	-2.8	0.9	≠ 0
12	1022	28.8	37.0	35.5	963	30.6	32.2	39.8	-59	1.8	-4.8	4.3	≠ 0
M	935	27.7	35.7	36.6	978	28.0	34.4	36.6	43	0.3	-1.3	1.6	12≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 37

Opposite Limb and Direction Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	1074	25.0	37.5	37.5	1254	27.2	36.6	36.0	180	2.2	.9	-1.5	≠ 0
2	1133	24.5	35.0	40.0	1193	24.2	37.0	39.0	60	-0.3	2.0	-1.0	≠ 0
3	863	24.3	36.5	37.6	960	26.6	39.3	36.0	97	2.3	2.8	-1.6	≠ 0
4	873	28.3	34.8	37.3	937	27.4	34.8	36.8	64	-0.9	1.2	-0.5	= 0
5	832	28.0	35.5	36.0	876	30.0	35.5	36.0	44	2.0	-0.1	0.0	= 0
6	976	26.8	35.8	36.3	1100	26.0	34.8	34.8	124	0.8	-1.0	-1.5	≠ 0
7	773	27.5	36.0	36.4	831	27.8	37.3	37.4	58	0.3	-1.3	1.0	= 0
8	949	35.3	34.0	31.0	1152	32.8	34.6	32.6	203	-2.5	-0.4	0.8	≠ 0
9	819	30.0	36.0	35.8	972	31.6	34.6	32.6	153	1.6	0.6	1.6	≠ 0
10	936	27.8	34.5	35.5	1080	27.8	32.8	35.6	144	0.0	1.7	0.1	= 0
11	797	22.8	36.3	36.5	846	25.4	33.8	38.4	49	2.6	-2.5	1.9	≠ 0
12	830	28.3	40.0	38.0	1030	28.2	37.5	36.2	200	-0.1	-2.5	-1.8	≠ 0
<u>M</u>	905	27.0	36.0	36.5	1019	28.0	35.9	36.3	114	1.0	-0.1	-0.2	8≠ 0

<u>Note.</u> Training trials include the last 40 trials of Day 2 performance.

Table 38

Reverse Direction Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	834	26.6	37.7	35.7	821	29.3	34.9	35.8	-13	2.7	-2.2	0.1	≠ 0
2	720	23.4	37.5	39.2	726	25.5	36.6	38.0	6	2.1	-0.9	-1.2	≠ 0
3	1235	28.6	37.0	37.4	1152	29.4	37.2	33.4	-103	0.8	3.2	-4.0	≠ 0
4	1151	26.3	36.1	37.6	1077	26.5	37.6	35.9	-74	0.2	1.5	-1.7	≠ 0
5	1222	28.2	33.6	38.2	1162	30.3	35.1	34.5	-60	2.1	1.6	-3.7	≠ 0
6	1009	33.0	32.8	34.1	1087	28.6	36.0	35.3	-22	-2.0	2.4	-0.2	≠ 0
7	1020	28.5	37.4	34.1	1087	28.6	36.0	35.3	61	-0.1	1.4	-1.2	= 0
8	1242	27.0	34.8	38.2	1270	28.7	37.8	33.5	28	1.7	3.0	-4.7	≠ 0
9	1043	27.9	35.1	37.1	1195	28.8	36.2	35.0	152	0.9	1.1	-2.1	≠ 0
10	817	23.5	40.2	36.3	837	24.7	38.0	37.3	20	1.2	-2.2	1.0	≠ 0
11	856	29.5	35.8	34.7	827	29.9	35.2	35.0	-29	0.4	-0.6	0.3	= 0
12	999	27.3	36.1	36.5	1004	27.8	37.0	35.1	5	0.5	0.9	-1.4	≠ 0
M	1012	27.5	35.9	36.6	1010	28.4	36.4	35.2	-2	0.9	0.9	-1.4	10≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

Table 39

Reverse Direction and Dimension Transfer

Mean Performance for Training and Transfer For Movement Segments 1, 2, 3

S	Training				Transfer				Change to Transfer				
	Total	Segment %			Total	Segment %			Total	Segment %			Slope
	MT	1	2	3	MT	1	2	3	MT	1	2	3	
1	1038	31.3	33.7	35.0	1148	35.3	37.7	27.0	110	4.0	4.0	-8.0	≠ 0
2	1023	26.5	35.2	38.3	1198	30.0	38.5	31.5	175	3.5	3.3	-6.8	≠ 0
3	870	23.2	37.6	39.2	920	29.2	38.3	32.5	50	6.0	0.7	-6.7	≠ 0
4	955	29.3	35.4	35.3	1035	35.0	36.5	32.5	80	5.7	1.1	-6.7	≠ 0
5	924	26.4	37.4	36.2	992	32.7	36.9	30.3	68	6.3	-0.5	-5.9	≠ 0
6	894	25.2	37.4	37.3	989	30.1	36.5	33.4	95	4.9	-0.9	-3.9	≠ 0
7	700	23.9	39.5	36.6	819	29.2	38.8	32.0	119	5.3	-0.7	-4.6	≠ 0
8	991	31.8	34.3	33.9	1018	32.2	36.4	31.4	27	0.4	2.1	-2.5	= 0
9	1182	25.8	37.1	37.1	1256	32.6	35.8	31.5	74	6.8	-1.3	-5.6	≠ 0
10	1145	37.0	30.5	32.4	1161	30.4	38.0	31.6	16	-5.6	6.5	0.8	≠ 0
11	1027	23.6	38.0	38.4	1191	28.0	38.1	33.9	164	4.4	0.1	-4.5	≠ 0
12	899	26.8	36.3	36.9	1064	31.3	40.4	28.3	142	4.5	4.1	-8.6	≠ 0
M	971	27.6	36.0	36.4	1064	31.3	37.6	31.0	93	3.7	1.6	-5.4	11≠ 0

Note. Training trials include the last 40 trials of Day 2 performance.

VITA

On July 31, 1956 in Athens, Alabama, Carol Ann Wood was born. She attended elementary and high school in Athens, Alabama. Following graduation from high school, she enrolled in the University of Alabama in Tuscaloosa and reeceived her B.S. degree in physical education in 1978. After three years of teaching in public schools, she enrolled in Auburn University and subseuently received a M.S. degree in physical education in 1982.

From 1982 to 1986, Carol was a teaching and research assistant at Louisiana State University while pursuing a Ph.D. degree in motor behavior with a minor in psychology. The Ph.D. degree was awarded August, 1986.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

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Major Field: HPERD (Motor Behavior)

Title of Dissertation: The role of task manipulations on the invariant phasing characteristics of a generalized motor program

Approved:

Richard A. Magill

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July 23, 1986